EXHIBIT A

US010076257B2

(12) **United States Patent**
Lin et al.

(10) **Patent No.: US 10,076,257 B2**
(45) **Date of Patent: *Sep. 18, 2018**

(54) **SEAMLESSLY EMBEDDED HEART RATE MONITOR**

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(73) Assignee: **APPLE INC.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 88 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **14/136,658**

(22) Filed: **Dec. 20, 2013**

(65) **Prior Publication Data**

US 2014/0171776 A1 Jun. 19, 2014

Related U.S. Application Data

(63) Continuation of application No. 12/358,905, filed on Jan. 23, 2009, now Pat. No. 8,615,290.
(Continued)

(51) **Int. Cl.**
A61B 5/117 (2016.01)
A61B 5/04 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***A61B 5/04012*** (2013.01); ***A61B 5/0245*** (2013.01); ***A61B 5/02438*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC A61B 5/02438; A61B 5/0245; A61B 5/404
(Continued)

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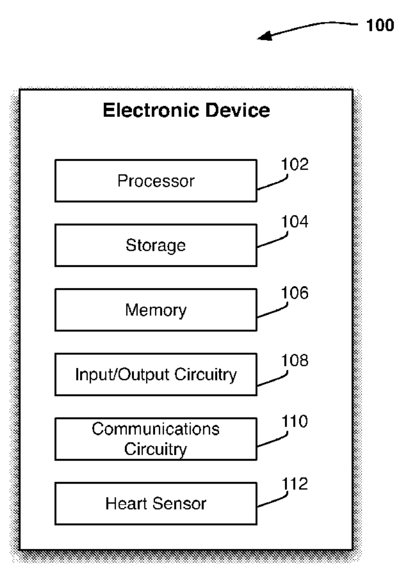
(74) *Attorney, Agent, or Firm* — Van Court & Aldridge LLP

(57) **ABSTRACT**

This is directed to an electronic device having an integrated sensor for detecting a user's cardiac activity and cardiac electrical signals. The electronic device can include a heart sensor having several leads for detecting a user's cardiac signals. The leads can be coupled to interior surfaces of the electronic device housing to hide the sensor from view, such that electrical signals generated by the user can be transmitted from the user's skin through the electronic device housing to the leads. In some embodiments, the leads can be coupled to pads placed on the exterior of the housing. The pads and housing can be finished to ensure that the pads are not visibly or haptically distinguishable on the device, thus improving the aesthetic qualities of the device. Using the detected signals, the electronic device can identify or authenticate the user and perform an operation based on the identity of the user. In some embodiments, the electronic device can determine the user's mood from the cardiac signals and provide data related to the user's mood.

22 Claims, 6 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 61/111,498, filed on Nov. 5, 2008.

(51) **Int. Cl.**

A61B 5/024	(2006.01)
A61B 5/0245	(2006.01)
A61B 5/0404	(2006.01)
A61B 5/0408	(2006.01)
A61B 5/044	(2006.01)
A61B 5/00	(2006.01)

(52) **U.S. Cl.**
CPC ***A61B 5/0404*** (2013.01); ***A61B 5/044*** (2013.01); ***A61B 5/04085*** (2013.01); ***A61B 5/6898*** (2013.01); *A61B 2560/0468* (2013.01)

(58) **Field of Classification Search**
USPC 607/36; 600/509
See application file for complete search history.

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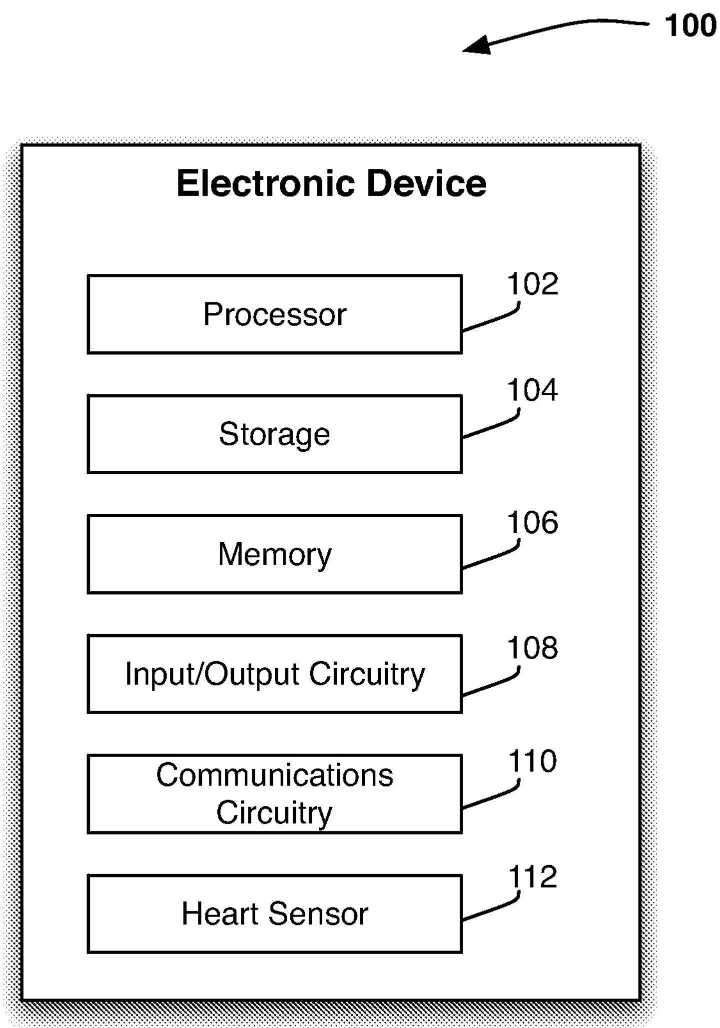
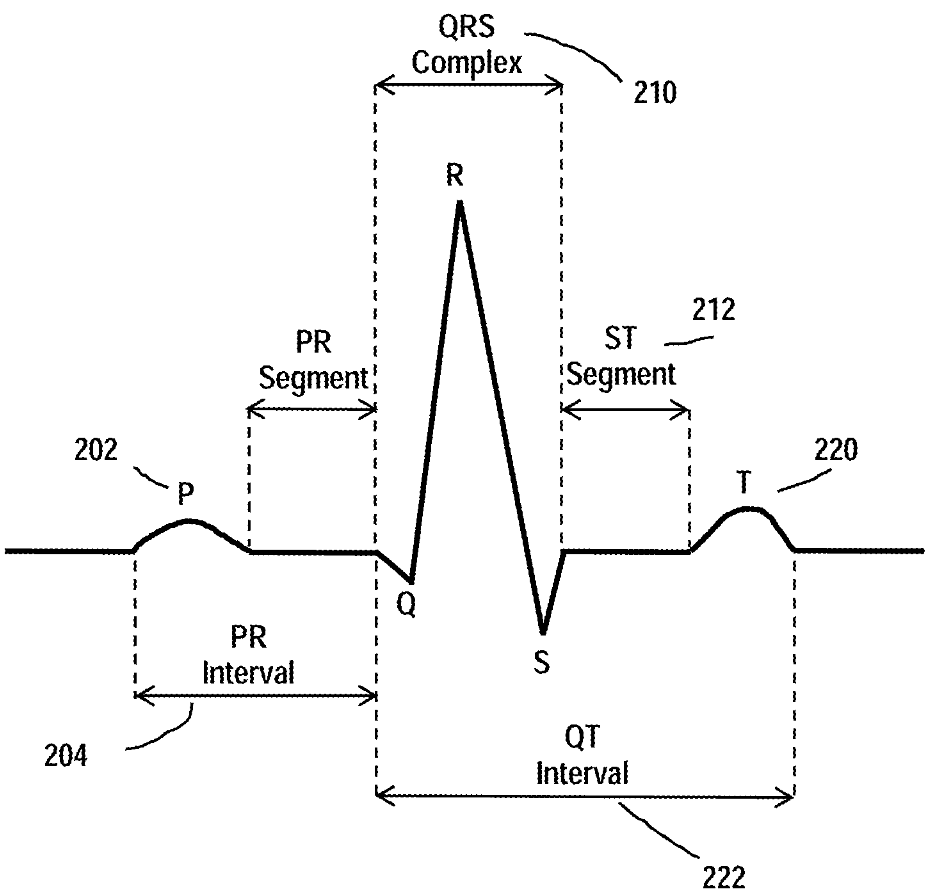

100
Electronic Device
Processor
102
Storage
104
Memory
106
Input/Output Circuitry
108
Communications Circuitry
110
Heart Sensor
112

FIG. 1


QRS
Complex
210
R
PR
Segment
ST
Segment
212
202
P
220
T
Q
S
PR
Interval
204
QT
Interval
222

200
FIG. 2

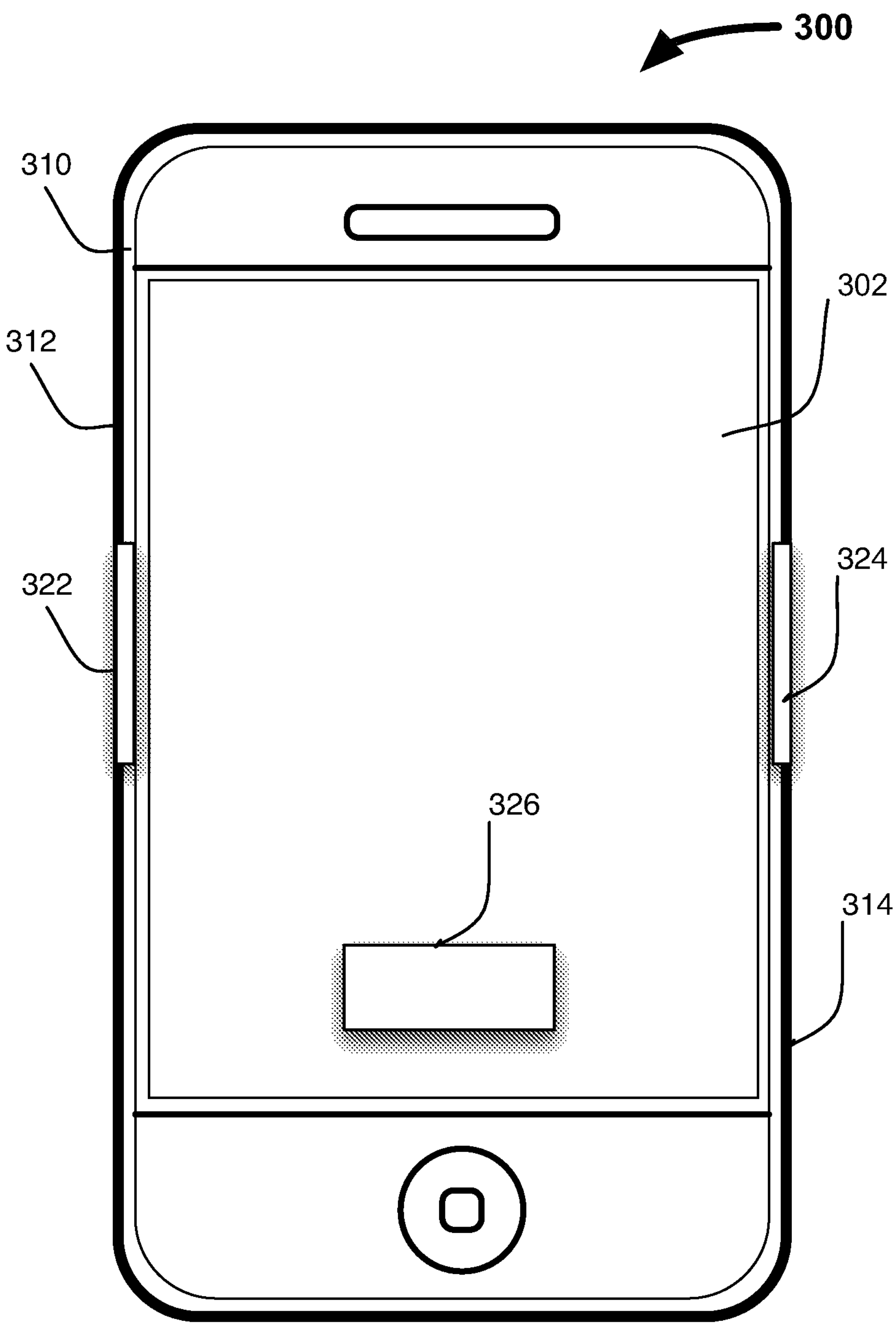


FIG. 3

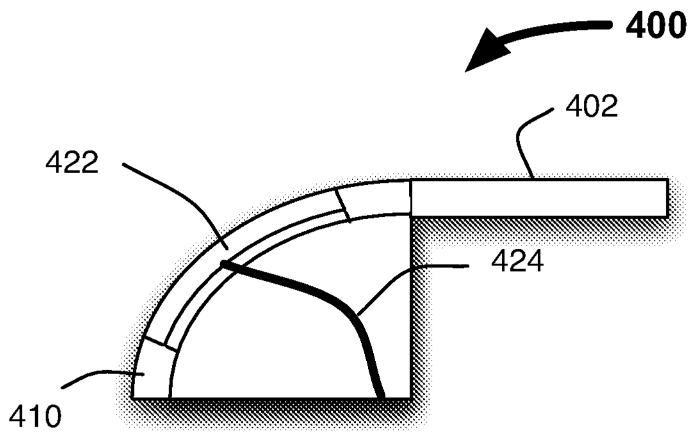


FIG. 4A

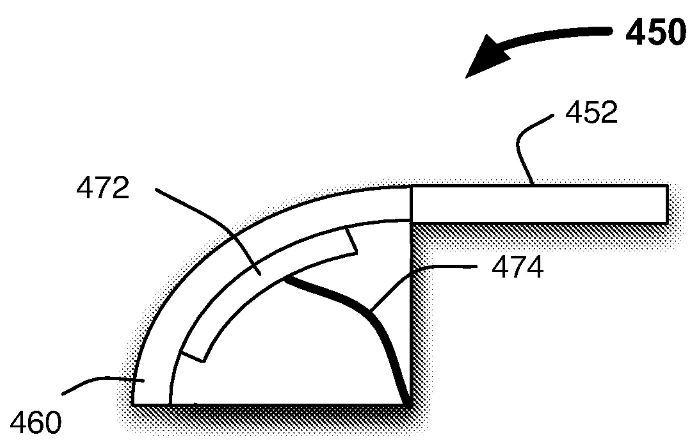


FIG. 4B

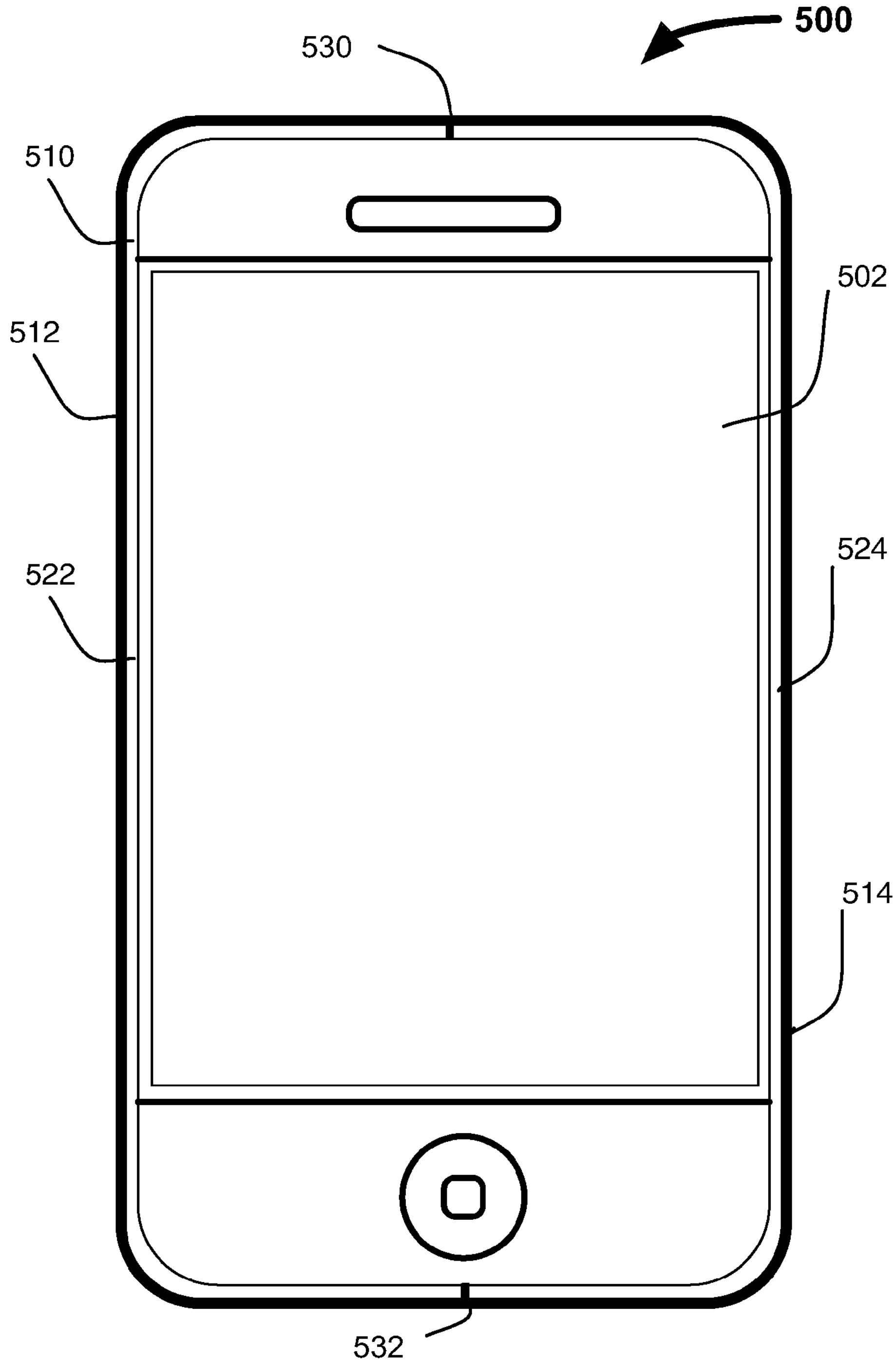
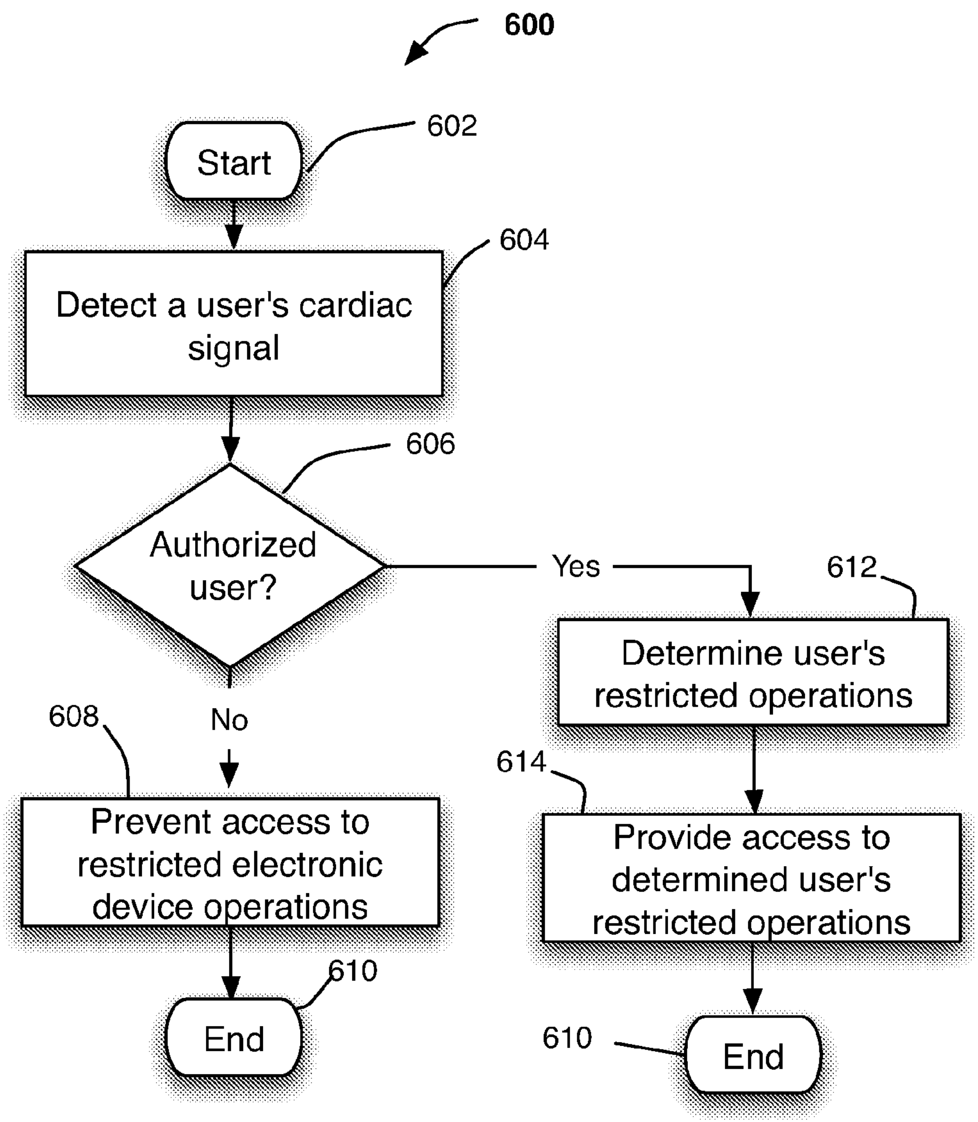


FIG. 5



600
Start
602
Detect a user's cardiac signal
604
Authorized user?
606
Yes
No
612
Determine user's restricted operations
608
Prevent access to restricted electronic device operations
614
Provide access to determined user's restricted operations
610
End
610
End

FIG. 6

SEAMLESSLY EMBEDDED HEART RATE MONITOR

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 12/358,905, filed Jan. 23, 2009 (now U.S. Pat. No. 8,615,290), which claims priority to U.S. Provisional Patent Application No. 61/111,498, filed Nov. 5, 2008. Each of these earlier applications is incorporated by reference herein in its entirety.

BACKGROUND OF THE INVENTION

This is directed to providing a seamless heart-rate monitor in an electronic device.

Many electronic devices are used to store personal or confidential information. In particular, portable electronic devices such as cellular telephones, personal assistants, and music players are often used to store or access e-mail, contact lists, communications history, remotely accessed accounts (e.g., telephone, banking or credit card accounts), or other information that a user may regard as personal or private. In addition, several users may use the same electronic device. For example, several users in a household may use the same computer or portable music player. As another example, a user may lend an electronic device to a friend (e.g., lend an iPod, available from Apple Inc. to a friend for a workout or a trip). To enhance each user's experience with the electronic device, the electronic device can include several profiles that can be loaded and provided to the users of the device. Each profile can be associated with a particular user, and include several settings that allow the electronic device interface user interaction components, and available data or applications to be personalized for the user.

The electronic device can use several approaches to identify the user of the electronic device and provide access to the user's private and personal information, or to load the user's personal profile. In some embodiments, the electronic device can identify or authenticate a user based on an input provided by the user, such as a password or key provided using an input mechanism. In some embodiments, the electronic device can include one or more sensors operative to detect a fingerprint, voice print, facial features, or other biometric characteristics of a user.

Other biometric-based approaches can be used to authenticate a user. In some embodiments, an electronic device can authenticate a user based on the attributes of the user's heartbeat. For example, the durations of particular portions of a user's heart rhythm, or the relative size of peaks of a user's electrocardiogram (EKG) can be processed and compared to a stored profile to authenticate a user of the device. To detect a user's heartbeat or heart rhythm, however, the electronic device must provide at least two leads that the user contacts to detect the user's cardiac signals. Although the leads can simply be placed on the exterior surface of the device housing, for example in a defined location where the user may place a finger, this approach is not aesthetically pleasing, and may cause some prospective buyers to consider other devices. In addition, such an approach may require the user to perform a specific authentication action—viz., placing a finger on the one or more leads, then unlocking or accessing the electronic device features (e.g., by moving a slider across the screen). This additional step

may in fact be so encumbering that users disable the authentication feature and instead use an unsecured electronic device.

SUMMARY OF THE INVENTION

This is directed to an electronic device having a seamlessly integrated cardiac sensor. The cardiac sensor can be integrated in any suitable portion of the electronic device, including for example a portion with which the user is typically in contact (e.g., an input mechanism or a housing held by the user), or metallic or conductive portions of the device.

The electronic device can include any suitable type of electronic device, including for example a portable electronic device that the user may hold in hand (e.g., a portable media player or a cellular telephone), a larger portable electronic device (e.g., a laptop computer), or a substantially fixed electronic device. The electronic device may include software or hardware operative to process the output of a cardiac sensor to extract, from the received output, characteristics of the user's heartbeat, heart rate, or other cardiac signals. For example, the electronic device may extract one or more characteristic durations associated with the user's heart rate. As another example, the electronic device may extract one or more characteristic amplitudes or amplitude ratios associated with the user's heart rate.

Once the electronic device has identified one or more characteristics of the user's heart rate, heartbeat, or other cardiac signals, the electronic device can compare the one or more identified characteristics with cardiac signal characteristics of authorized users that have been stored in memory. In response to determining that the identified characteristics correspond to those of an authorized user (e.g., match those stored in memory), the electronic device can provide the user with access to the electronic device and load the identified user's personal settings and data.

To determine the user's heart rate, heartbeat, or other cardiac signals, the electronic device can include one or more sensors embedded in the device. The one or more sensors can include leads for receiving electrical signals from the user's heart. For example, the one or more sensors can include leads associated with the user's left and right sides, and lead associated with the ground. To provide an electrical signal from the user to the processing circuitry, the leads can be exposed such that the user may directly contact the leads, or may instead or in addition be coupled to an electrically conductive portion of the device enclosure (e.g., a metallic bezel or housing forming the exterior of the device).

Because each electronic device can include several leads, the leads may be electrically isolated to avoid shorting or interference among leads. In some embodiments, an electrically isolating component can be inserted between adjacent leads. Alternatively, if the electronic device enclosure is constructed from a material having insufficient conductivity for transmitting detected cardiac electrical signals, the distance along the enclosure between adjacent leads can be sufficient to isolate the leads. In addition, to ensure that the aesthetic appeal and appearance of the electronic device is retained, one or more of the isolating components, the leads themselves, and the device enclosure can be finished using a suitable process to disguise the leads.

In some embodiments, if the electrical conductivity of portions of the electronic device enclosure and the leads are suitably selected and designed, the leads can be positioned underneath the exterior surface of the enclosure while pro-

viding sufficient conductivity for detecting cardiac electrical signals and avoiding shorting or interference between adjacent leads. For example, the sensor leads can be constructed from a silver based compound having high electrical conductivity, while the electronic device enclosure can be constructed from steel and aluminum, both having lower electrical conductivity. By placing several leads at substantially larger distances apart along the electronic device enclosure than the thickness of the enclosure, electronic signals can be transmitted through the steel or aluminum enclosure to a silver based lead underneath the enclosure, but not along the surface of the enclosure to cause adjacent leads to short.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features of the present invention, its nature and various advantages will be more apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings in which:

FIG. **1** is a schematic view of an illustrative electronic device for receiving the output of one or more sensors in accordance with one embodiment of the invention;

FIG. **2** is a graphical representation of illustrative electrical activity of a heart during a heartbeat;

FIG. **3** is a schematic view of an illustrative electronic device having several integrated leads in accordance with one embodiment of the invention;

FIG. **4**A is a cross-sectional view of an illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention;

FIG. **4**B is a cross-sectional view of another illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention;

FIG. **5** is a schematic view of an illustrative electronic device using portions of the bezel as leads in accordance with one embodiment of the invention; and

FIG. **6** is a flowchart of an illustrative process for performing an electronic device operation based on a user's cardiac signal in accordance with one embodiment of the invention.

DETAILED DESCRIPTION

FIG. **1** is a schematic view of an illustrative electronic device for receiving the output of one or more sensors in accordance with one embodiment of the invention. Electronic device **100** can include control circuitry **102**, storage **104**, memory **106**, input/output circuitry **108**, communications circuitry **110**, and heart sensor **112**. In some embodiments, one or more of electronic device components **100** can be combined or omitted (e.g., combine storage **104** and memory **106**). In some embodiments, electronic device **100** can include other components not combined or included in those shown in FIG. **1** (e.g., motion detection components, a power supply such as a battery or kinetics, a display, bus, or input mechanism), or several instances of the components shown in FIG. **1**. For the sake of simplicity, only one of each of the components is shown in FIG. **1**.

Control circuitry **102** can include any processing circuitry or processor operative to control the operations and performance of electronic device **100**. For example, control circuitry **100** can be used to run operating system applications, firmware applications, media playback applications, media editing applications, or any other application. In some embodiments, the control circuitry can drive a display and process inputs received from a user interface.

Storage **104** can include, for example, one or more storage mediums including a hard-drive, solid state drive, flash memory, permanent memory such as ROM, any other suitable type of storage component, or any combination thereof. Storage **104** can store, for example, media data (e.g., music and video files), application data (e.g., for implementing functions on device **100**), firmware, user preference information data (e.g., media playback preferences), authentication information (e.g. libraries of data associated with authorized users), lifestyle information data (e.g., food preferences), exercise information data (e.g., information obtained by exercise monitoring equipment), transaction information data (e.g., information such as credit card information), wireless connection information data (e.g., information that can enable electronic device **100** to establish a wireless connection), subscription information data (e.g., information that keeps track of podcasts or television shows or other media a user subscribes to), contact information data (e.g., telephone numbers and email addresses), calendar information data, and any other suitable data or any combination thereof.

Memory **106** can include cache memory, semi-permanent memory such as RAM, and/or one or more different types of memory used for temporarily storing data. In some embodiments, memory **106** can also be used for storing data used to operate electronic device applications, or any other type of data that can be stored in storage **104**. In some embodiments, memory **106** and storage **104** can be combined as a single storage medium.

Input/output circuitry **108** can be operative to convert (and encode/decode, if necessary) analog signals and other signals into digital data. In some embodiments, input/output circuitry **108** can also convert digital data into any other type of signal, and vice-versa. For example, input/output circuitry **108** can receive and convert physical contact inputs (e.g., from a multi-touch screen), physical movements (e.g., from a mouse or sensor), analog audio signals (e.g., from a microphone), or any other input. The digital data can be provided to and received from processor **102**, storage **104**, memory **106**, heart sensor **112**, or any other component of electronic device **100**. Although input/output circuitry **108** is illustrated in FIG. **1** as a single component of electronic device **100**, several instances of input/output circuitry can be included in electronic device **100**.

Electronic device **100** can include any suitable mechanism or component for allowing a user to provide inputs to input/output circuitry **108**. For example, electronic device **100** can include any suitable input mechanism, such as for example, a button, keypad, dial, a click wheel, or a touch screen. In some embodiments, electronic device **100** can include a capacitive sensing mechanism, or a multi-touch capacitive sensing mechanism. Some sensing mechanisms are described in commonly owned U.S. Pat. Nos. 8,479,122 and 8,239,784, both of which are incorporated herein in their entirety.

In some embodiments, electronic device **100** can include specialized output circuitry associated with output devices such as, for example, one or more audio outputs. The audio output can include one or more speakers (e.g., mono or stereo speakers) built into electronic device **100**, or an audio component that is remotely coupled to electronic device **100** (e.g., a headset, headphones or earbuds that can be coupled to communications device with a wire or wirelessly).

In some embodiments, I/O circuitry **108** can include display circuitry (e.g., a screen or projection system) for

providing a display visible to the user. For example, the display circuitry can include a screen (e.g., an LCD screen) that is incorporated in electronics device **100**. As another example, the display circuitry can include a movable display or a projecting system for providing a display of content on a surface remote from electronic device **100** (e.g., a video projector). In some embodiments, the display circuitry can include a coder/decoder (Codec) to convert digital media data into analog signals. For example, the display circuitry (or other appropriate circuitry within electronic device **100**) can include video Codecs, audio Codecs, or any other suitable type of Codec.

The display circuitry also can include display driver circuitry, circuitry for driving display drivers, or both. The display circuitry can be operative to display content (e.g., media playback information, application screens for applications implemented on the electronic device, information regarding ongoing communications operations, information regarding incoming communications requests, or device operation screens) under the direction of control circuitry **102**. Alternatively, the display circuitry can be operative to provide instructions to a remote display (e.g., display **130**, FIG. **1**).

Communications circuitry **110** can include any suitable communications circuitry operative to connect to a communications network and to transmit communications (e.g., voice or data) from communications device **100** to other devices within the communications network. Communications circuitry **110** can be operative to interface with the communications network using any suitable communications protocol such as, for example, Wi-Fi (e.g., a 802.11 protocol), Bluetooth, radio frequency systems (e.g., 900 MHz, 1.4 GHz, and 5.6 GHz communication systems), infrared, GSM, GSM plus EDGE, CDMA, quadband, and other cellular protocols, VOIP, or any other suitable protocol.

In some embodiments, communications circuitry **110** can be operative to create a communications network using any suitable communications protocol. For example, communications circuitry **110** can create a short-range communications network using a short-range communications protocol to connect to other devices. For example, communications circuitry **110** can be operative to create a local communications network using the Bluetooth® protocol to couple electronic device **100** with a Bluetooth headset.

Electronic device **100** can include one more instances of communications circuitry **110** for simultaneously performing several communications operations using different communications networks, although only one is shown in FIG. **1** to avoid overcomplicating the drawing. For example, electronic device **100** can include a first instance of communications circuitry **110** for communicating over a cellular network, and a second instance of communications circuitry **110** for communicating over Wi-Fi or using Bluetooth®. In some embodiments, the same instance of communications circuitry **110** can be operative to provide for communications over several communications networks.

In some embodiments, electronic device **100** can be coupled a host device for data transfers, synching the communications device, software or firmware updates, providing performance information to a remote source (e.g., providing riding characteristics to a remove server) or performing any other suitable operation that can require electronic device **100** to be coupled to a host device. Several electronic devices **100** can be coupled to a single host device using the host device as a server, and instead or in addition electronic device **100** can be coupled to several host devices (e.g., for each of the plurality of the host devices to serve as a backup for data stored in electronic device **100**).

Heart sensor **112** can include any suitable sensor operative to detect a user's heartbeat, heart rate, or any other signal generated by the user's heart. In some embodiments, heart sensor **112** can serve as an EKG monitor. Heart sensor **112** can include one or more leads connected to the exterior of the electronic device such that the user may contact one or more of the leads to provide an electrical signal associated with the user's heart to heart sensor **112**. The cardiac signals detected by the heart sensor leads can be coupled to a processor incorporated in heart sensor **112**, or instead provided to processor **102**. The processor may then analyze the received signals and generate, from the received signals, one or more characteristic quantities of the user's heartbeat or heart rate for authentication.

The heart sensor leads can be constructed from any suitable material. In some embodiments, the heart sensor leads can be constructed from a specific material selected for particular conductive properties that permit a more effective transmission of the electrical signals reflecting the user's cardiac activity. For example, the heart sensor leads can be constructed from a silver based compound, which can provide superior conductivity relative to other metallic compounds (e.g., steel or aluminum). In addition, the size and location of the leads can be selected to ensure that sufficient contact is made between the user (e.g., the user's hand or finger) and the leads for cardiac signals to be detected. For example, each lead can include a pad or extended area placed on the outer or inner surface of an electronic device bezel or housing. The pad or extended area can then be coupled to a wire or other connector for providing cardiac signals to a processor for processing. As another example, an entire portion of the electronic device enclosure (e.g., a portion of a bezel or housing) can serve as a lead for the heart sensor. In such embodiments, the portion of the enclosure can be sufficiently electrically isolated from other conductive portions of the electronic device housing to ensure that lead portions of the device do not short. In some embodiments, an accessory coupled to the electronic device can be used to detect a user's heart rate. For example, the leads can be located in one or more earbuds or in a headset, for example as is described in commonly assigned U.S. Publication No. 2008/0076972, which is incorporated by reference herein in its entirety.

Using a heart sensor, the electronic device can detect and analyze the electrical activity of the heart over time. FIG. **2** is a graphical representation of illustrative electrical activity of a heart during a heartbeat. Representation **200** may include a plot of the variation of the heart's electrical potential over time. A typical heartbeat may include several variations of electrical potential, which may be classified into waves and a complex. For example, representation **200** can include P wave **202**, QRS complex **210**, and I wave **220**. Some representations can in addition include a U wave (not shown). The P wave can represent normal atrial depolarization, when the main electrical vector spreads from the right atrium to the left atrium. The shape and duration of the P wave can be related to the size of the user's atrium (e.g., indicating atrial enlargement), and can be a first source of heartbeat characteristics unique to a user.

The QRS complex can correspond to the depolarization of the heart ventricles, and can be separated into three distinct waves—a Q wave, a R wave and a S wave. Because the ventricles contain more muscle mass than the atria, the QRS complex is larger than the P wave. In addition, the His/Purkinje system of the heart, which can increase the con-

duction velocity to coordinate the depolarization of the ventricles, can cause the QRS complex to look "spiked" rather than rounded. The duration of the QRS complex of a healthy heart can be in the range of 60 to 100 ms, but can vary due to abnormalities of conduction. The duration of the QRS complex can therefore serve as a second source of heartbeat characteristics unique to a user.

The duration, amplitude, and morphology of each of the Q, R and S waves can vary in different individuals, and in particular can vary significantly for users having cardiac diseases or cardiac irregularities. For example, a Q wave that is greater than ⅓ of the height of the R wave, or greater than 40 ms in duration can be indicative of a myocardial infarction and provide a unique characteristic of the user's heart. Similarly, other healthy ratios of Q and R waves can be used to distinguish different users' heartbeats.

Representation **200** may include one or more characteristic durations or intervals that can be used to distinguish different users. For example, representation **200** can include PR interval **204** and ST segment **212**. PR interval **204** can be measured from the beginning of P wave **202** to the beginning of QRS complex **210**. PR interval **204** can typically last **120** to 200 ms. A PR interval **204** having a different duration can indicate one or more defects in the heart, such as a first degree heart block (e.g., PR interval **204** lasting more than 200 ms), a pre-excitation syndrome via an accessory pathway that leads to early activation of the ventricles (e.g., PR interval **204** lasts less than 120 ms), or another type of heart block (e.g., PR interval **204** is variable). ST segment **212** can be measured from QRS complex **210** to T wave **220**, for example starting at the junction between QRS complex **210** and ST segment **212** and ending at the beginning of T wave **220**. ST segment **212** can typically last from 80 to 120 ms, and normally has a slight upward concavity. The combination of the length of ST segment **212**, and the concavity or elevation of ST segment **212** can also be used to generate characteristic information unique to each user's heartbeat.

T wave **220** can represent the repolarization or recovery of the ventricles. The interval from the beginning of the QRS complex to the apex of the T wave can be referred to as the absolute refractory period. The last half of the T wave can be referred to as the relative refractory period or vulnerable period. The amplitude of T wave **220**, the duration of the absolute refractory period, and the relative refractory period can also be used to define a characteristic of the user's heart rate.

QT interval **222**, which can represent the total time needed for the ventricles to depolarize and repolarize, can be measured from the beginning of QRS complex **210** to the end of T wave **220**. QT interval **222** can typically last between 300 and 450 ms, and can vary based on the condition of the user's heart rate. Several correction factors have been developed to correct QT interval **222** for the heart rate. Both the measured and corrected QT interval **222** values can be used to define a unique characteristic of a user's heartbeat.

Because a user's heartbeat or heart rate can vary slightly based on the user's activity or mood, each authorized user can initially provide a base or standard heart rate, heartbeat, or electrical activity to the device prior to first use. For example, the electronic device can sample several heartbeats or electrical activity at several different times to detect variations in the user's cardiac electrical activity. The electronic device can process detected signals to determine several unique characteristics of the user's heart activity, and identify a range of suitable characteristic values for each of the processed characteristics. Based on the characteristic values and associated ranges, the electronic device can select one, all or a subset of the characteristics to define a unique heart activity profile for the authorized user. The particular combination of characteristics and associated ranges can be selected to minimize overlap with other authorized users, or based on characteristic values and ranges that do not fall within a range of average values and ranges (e.g., do not use characteristic values and ranges that an average user of the device would have).

The heart sensor of the electronic device can include several leads for detecting the user's heart activity. The leads can be integrated in any suitable portion of the electronic device. FIG. **3** is a schematic view of an illustrative electronic device having several integrated leads in accordance with one embodiment of the invention. Electronic device **300** can include display **302** and bezel **310**, and be portable such that a user can hold electronic device with fingers extending against one of sides **312** and **314** of bezel **310**, and the user's thumb extending against the other of sides **312** and **314**. Leads **322** and **324**, which can include conductive pads, can be coupled to sides **312** and **314** of bezel **310**, respectively, such that when the user holds the device, the user's thumb and fingers are placed in contact with leads **322** and **324**. Alternatively, bezel **310** can include any other suitable number of leads, or any other suitable distribution of leads along bezel **310** and in other portions of electronic device **300**. The leads can detect the user's cardiac activity through the contact with the user's thumb and fingers, and provide the detected activity to the electronic device processor for processing. The size of leads **322** and **324** can be selected based on any suitable consideration, including for example the different possible positions of a user's hands on the device, the amount of contact necessary to detect the user's cardiac activity, preventing or reducing short circuits and other cardiac signal detection errors, manufacturing considerations (e.g., the minimum or maximum size leads that can be integrated in the bezel), aesthetic considerations (e.g., sizing leads **322** and **324** to reduce the visibility of leads **322** and **324**), or any other suitable consideration.

In some embodiments, electronic device **300** can include additional lead **326** embedded in or behind display **302**. Lead **326** can be operative to detect a user's heart activity as the user moves a finger across display **302**, for example in the vicinity of or directly over lead **326** (e.g., as the user drags a finger over lead **326** to move a slider when unlocking the electronic device). Using lead **326**, the electronic device can detect an electrical signal from a different portion of the user's body (e.g., leads **322** and **324** detect signals through a first hand, and lead **326** detects signals through the second hand), which can provide the processor with additional information for determining characteristics of the user's cardiac activity.

Any suitable approach can be used to prevent leads **322**, **324** and **326** from shorting. In particular, electronic device **300** can include at least one non-conductive component positioned between each of leads **322**, **324** and **326**. For example, a rubber gasket can be positioned between leads **322** and **324** (in bezel **310**) and lead **326** (in display **302**). In some embodiments, the cardiac electrical signals detected by leads **322**, **324** and **326** can be faint or have particular characteristics that require materials having particular properties (e.g., silver-based compounds) to detect and transmit. In such cases, although the material used for bezel **310** or other electronic device components can be conductive, its conductivity can be insufficient to transmit signals detected by lead **322** directly to lead **324** (e.g., shorting leads **322** and **324**). This may allow leads **322** and **324** to be embedded

directly in bezel **310** without the need for additional isolating material, which can add cost and complexity to the manufacturing process.

To ensure that electronic device **300**, and in particular bezel **310** remains aesthetically pleasing, leads **322** and **324** can be finished to resemble bezel **310**. For example, leads **322** and **324** can be polished or roughened to match the finish of bezel **310**. As another example, a conductive coating can be applied to leads **322** and **324** to match the color, tone and reflectivity of bezel **310**. In some embodiments, the texture or feel of leads **322** and **324** can also be selected to render leads **322** and **324** visibly and haptically indistinguishable or nearly indistinguishable from bezel **310**.

Leads **322** and **324** can be integrated in bezel **310** using any suitable approach. In some embodiments, leads **322** and **324** can be positioned on the exterior surface of bezel **310** and include an electrically conductive path to the electronic device processor. FIG. **4**A is a cross-sectional view of an illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention. Electronic device **400** can include display **402** and bezel **410**. Lead **422** can be embedded along the outer surface of bezel **410** such that lead **422** is exposed to the user during use. Connector **424** can be coupled to the inner surface of lead **422** and extend into electronic device **400** to be coupled with a processor. In some embodiments, electronic device **400** can in addition include an isolating layer positioned between lead **422** and bezel **410** (not shown). The isolating layer can be constructed from any suitable material having non-conductive properties, including for example a ceramic material, plastic, rubber, or any other suitable material. Alternatively, if the material of bezel **410** is not conductive, or insufficiently conductive to cause several distinct leads **422** positioned on bezel **410** from shorting, no isolating layer may be necessary.

FIG. **4**B is a cross-sectional view of another illustrative electronic device having a bezel with an embedded heart sensor lead in accordance with one embodiment of the invention. Electronic device **450** can include display **452** and bezel **460**. If the electrical conductivity and size of bezel **460**, and the strength or characteristics of the cardiac signal provided by the user and detected by the heart sensor are adapted such that the signal can be transmitted along short distances in bezel **460**, lead **472** of the heart sensor can be positioned against the back surface of bezel **460**. Alternatively, lead **472** can be placed within the thickness of bezel **460** (e.g., in a pocket within the bezel wall), but underneath the outer surface of the bezel. The short thickness of bezel **460** can allow electrical signals to propagate from the user to the outer surface of bezel **460**, through bezel **460**, and into lead **472**, which may in turn transmit the signals to a processor using connector **474**. In addition, if several leads are placed along different portions of bezel **460**, the distance between adjacent leads can be sufficiently large (e.g., substantially larger than the thickness of bezel **460**) that different leads of bezel **460** cannot detect the same electrical signal.

In some embodiments, entire portions of the bezel can be used as leads for the heart sensor. FIG. **5** is a schematic view of an illustrative electronic device using portions of the bezel as leads in accordance with one embodiment of the invention. Similar to electronic device **300** (FIG. **3**), electronic device **500** can include display **502** and bezel **510**. Bezel **510** can be separated into several electrically isolated segments, for example segments **522** and **524**. The segments can be electrically isolated using isolating portions **530** and **532**, which can be constructed from any suitable non-

conductive material, such as for example a composite material, a plastic, rubber, or any other suitable material. Although FIG. **5** shows bezel **510** broken into two segments having similar sizes, it will be understood that bezel **510** can be separated into any suitable number of electrically isolated segments, and each segment can have any suitable size. In particular, the sizes and distribution of each segment can be selected based on physiological considerations (e.g., where a user's hand will be positioned on the device, or aligning the segments to contact particular portions of the user's body).

To ensure that electronic device **500** remains aesthetically pleasing, isolating portions **530** and **532** can be finished to resemble bezel **510**. For example, isolating portions **530** and **532** can be polished or machined to create a reflective surface matching the reflection of bezel **510**. As another example, a reflective or finishing coating can be applied to the surfaces of isolating portions **530** and **532** to match the finish of bezel **510**. In some embodiments, the texture of isolating portions **530** and **532** can also be selected to render segments **522** and **524** visually and haptically indistinguishable or nearly indistinguishable from isolating portions **530** and **532**.

Other heart sensor leads can be placed at any other suitable position on the electronic device enclosure. For example, if the enclosure is constructed from a bezel supporting a display and a housing forming the exterior surface of the device behind the display, one or more leads can be embedded in or adjacent to the housing. For example, if the housing includes a conductive section (e.g., a plastic housing with a metallic logo in the center of the housing), the lead can be coupled to or integrated in the conductive section.

The heart sensor and processor can detect and process the user's cardiac activity at any suitable time. For example, the processor can receive and process heart activity when the device is locked and held while in its locked state. As another example, the processor can receive and process heart activity as the user places a finger over lead **326** (e.g., when the user slides a finger across the display to unlock the device) or when an input mechanism detects a particular input. As still another example, the electronic device can receive and process heart activity data in response to a user instruction or request to access a particular application or data that for which access is restricted. Upon receiving the cardiac activity, the electronic device can extract one or more characteristics of the received activity and compare the extracted characteristics with the characteristics previously stored in memory that were associated with authorized users. If the extracted characteristics match those of an authorized user, the electronic device can authenticate the identified user.

The electronic device can perform any suitable operation in response to identifying and authenticating a user based on detected cardiac signals. In some embodiments, the electronic device can provide access to restricted applications, for example applications for which only particular users have licenses or that only particular users have purchased. In some embodiments, the electronic device can provide access to particular data or application settings associated with an authorized user. For example, the electronic device can provide access to the identified user's contact list, or to the identified user's e-mail account or telephone history. As another example, the electronic device can allow the user to access private banking applications, or conduct financial transactions (e.g., transferring funds to different accounts, or purchasing merchandise) using the electronic device. In

some embodiments, the electronic device can load user settings and profiles for providing a customized display to the user. For example, the electronic device can display icons or options in the manner set by the user, or provide displays using a color scheme, fonts, or other customizable display attribute that are associated with the identified user.

In some embodiments, the electronic device can use the detected heart rate or heartbeat characteristics to determine the user's mood. In particular, because the allowable determined characteristics associated with each user can include a range of values, the electronic device can determine the distribution of the detected characteristics in the allowable characteristic ranges. Using the determined distribution, the electronic device can establish a user's mood and provide electronic device operations or data (e.g., media) associated with the extrapolated mood. Systems and methods for providing mood-based electronic device operations are discussed in more detail in commonly assigned U.S. Publication No. 2010/0011388, which is incorporated by reference herein in its entirety.

In some embodiments, the electronic device can provide media playback based on the user's detected cardiac signal. For example, the electronic device can identify media having beats per minute or other characteristics that are associated with or related to the user's cardiac signal or heart rate, and play back the identified media. As another example, the media provided can have beats per minute faster or slower than the user's current heart rate to direct the user to work harder (e.g., during a workout) or to cool or calm the user down (e.g., at the end of a workout).

FIG. **6** is a flowchart of an illustrative process for performing an electronic device operation based on a user's cardiac signal in accordance with one embodiment of the invention. Process **600** can begin at step **602**. At step **604**, the electronic device can detect a user's cardiac signal. For example, the electronic device can detect a user's heart rate or heart beat using one or more leads connected to or placed on a housing, bezel, or other exterior surface of the electronic device. The electronic device can process the received signal using any suitable approach, including for example to determine unique characteristics of the signal. Such characteristics can include, for example, durations between peaks in an EKG signal, peak values or rations between peaks in the EKG signal, or any other suitable characteristic. At step **606**, the electronic device can determine whether the user detected at step **604** is an authorized user. For example, the electronic device can compare the determined characteristics of the detected cardiac signals with a library of signals associate with known authorized users. If the electronic device determines that the user is not authorized (e.g., the characteristics of the detected cardiac signal do not match characteristics of a cardiac signal stored in memory), process **600** can move to step **608**.

At step **608**, the electronic device can prevent access to restricted electronic device operations. For example, the electronic device can prevent the user from accessing personal or private information associated with other users. As another example, the electronic device can prevent the user from accessing applications or operations associated with particular users (e.g., applications purchased by particular users). As still another example, the electronic device can prevent the user from accessing any electronic device operation (e.g., no operation except for emergency calls). Process **600** can then end at step **610**.

If, at step **606**, the electronic device instead determines that the user is authorized, process **600** can move to step **612**. At step **612**, the electronic device can determine the restricted operations that are associated with the user. For example, the electronic device can determine the particular private data associated with the authorized user (e.g., e-mail accounts, contact lists and banking information). As another example, the electronic device can determine the particular operations or applications associated with the authorized user (e.g., applications purchased by the user using an applications store, or system controlling operations associated with an administrative account). At step **614**, the electronic device can provide access to the user's determined restricted operations. For example, the electronic device can load determined data. As another example, the electronic device can provide links for launching determined personal or private applications. Process **600** can then end at step **610**.

The above-described embodiments of the present invention are presented for purposes of illustration and not of limitation, and the present invention is limited only by the claims which follow.

What is claimed is:

1. An electronic device for detecting a user's cardiac signal, comprising:

an enclosure;

a heart sensor configured to detect the user's cardiac signal, the heart sensor comprising:

a first lead comprising a first pad that is embedded in a first portion of the enclosure, wherein an exterior surface of the enclosure comprises an exterior surface of the first portion, wherein the first pad is positioned underneath the exterior surface of the first portion, and wherein the first pad is configured to detect a first electrical signal of the user's cardiac signal via the user's skin's contact with the exterior surface of the first portion of the enclosure; and

a second lead comprising a second pad that is embedded in a second portion of the enclosure, wherein the second pad is configured to detect a second electrical signal of the user's cardiac signal via the user's skin's contact with at least one of the second pad and the second portion of the enclosure; and

a processor coupled to the heart sensor and configured to receive and process the detected cardiac signal, wherein the first lead further comprises a first connector coupled to the first pad and configured to provide the first electrical signal detected by the first pad to the processor, and wherein the second lead further comprises a second connector coupled to the second pad and configured to provide the second electrical signal detected by the second pad to the processor.

2. The electronic device of claim **1**, wherein the first portion and the second portion are located on opposite sides of the electronic device.

3. The electronic device of claim **1**, wherein the first portion is electrically isolated from the second portion.

4. The electronic device of claim **1**, wherein:

the first portion is separated from the second portion by a third portion of the enclosure;

at least the third portion is constructed from a material having a first conductivity; and

the first conductivity is insufficient to transmit the first electrical signal from the first pad to the second pad via the third portion.

5. The electronic device of claim **4**, wherein:

the material having the first conductivity comprises one of aluminum and steel; and

the second pad is constructed from a silver based compound.

6. The electronic device of claim **4**, wherein:

the exterior surface of the enclosure further comprises an exterior surface of the second portion;

the second pad is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the exterior surface of the second portion;

the second pad is positioned from the exterior surface of the second portion by a thickness of the second portion;

at least the thickness of the second portion is constructed from material having a second conductivity; and

the second conductivity is defined such that the second electrical signal is not able to be transmitted through material having the second conductivity over a distance larger than the thickness of the second portion.

7. The electronic device of claim **6**, wherein the first pad and the second pad are positioned apart from one another at a distance larger than the thickness of the second portion by material having the second conductivity.

8. The electronic device of claim **1**, wherein:

the enclosure further comprises at least one pocket underneath the exterior surface of the enclosure; and

at least one of the first pad and the second pad is placed within the at least one pocket.

9. The electronic device of claim **1**, further comprising:

a display, wherein the enclosure supports the display, and wherein at least a portion of the exterior surface of the enclosure forms at least a portion of an exterior surface of the electronic device behind the display; and

a third lead embedded with the display, wherein the third lead is configured to detect a third electrical signal of the user's cardiac signal via the user's contact with at least one of the third lead and the display.

10. The electronic device of claim **1**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the second portion of the enclosure.

11. The electronic device of claim **1**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the second lead.

12. The electronic device of claim **1**, wherein the first portion of the enclosure is a bezel.

13. The electronic device of claim **1**, wherein the second portion of the enclosure is a bezel.

14. The electronic device of claim **1**, wherein an interior surface of the enclosure comprises an interior surface of the first portion, wherein the first pad is positioned on the interior surface of the first portion.

15. An electronic device for detecting a user's cardiac signal, comprising:

an enclosure;

a display screen exposed to the user through an opening in the enclosure;

a heart sensor configured to detect the user's cardiac signal, the heart sensor comprising:

a first lead embedded in a first portion of the enclosure of the electronic device, wherein the first lead is configured to detect a first electrical signal of the user's cardiac signal via the user's contact with at least one of the first lead and the first portion of the enclosure of the electronic device; and

a second lead embedded in the display screen of the electronic device, wherein the second lead is configured to detect a second electrical signal of the user's cardiac signal via the user's contact with at least one of the second lead and the display screen of the electronic device; and

a processor coupled to the heart sensor and configured to process the first and second electrical signals of the user's cardiac signal.

16. The electronic device of claim **15**, wherein the first lead is configured to detect the first electrical signal of the user's cardiac signal via the user's contact with the first lead.

17. The electronic device of claim **16**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the second lead.

18. The electronic device of claim **16**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the display screen.

19. The electronic device of claim **15**, wherein:

the first portion of the electronic device comprises a bezel of the enclosure;

the electronic device further comprises a non-conductive component positioned between the bezel and the display screen for electrically isolating the first lead from the second lead.

20. The electronic device of claim **15**, wherein the first lead is configured to detect the first electrical signal of the user's cardiac signal via the user's contact with the first portion of the enclosure.

21. The electronic device of claim **20**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the second lead.

22. The electronic device of claim **20**, wherein the second lead is configured to detect the second electrical signal of the user's cardiac signal via the user's contact with the display screen.

* * * * *

EXHIBIT B

US010627783B2

(12) **United States Patent**
Rothkopf et al.

(10) **Patent No.: US 10,627,783 B2**
(45) **Date of Patent: Apr. 21, 2020**

(54) **WEARABLE ELECTRONIC DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/261,917**

(22) Filed: **Sep. 10, 2016**

(65) **Prior Publication Data**

US 2016/0378071 A1 Dec. 29, 2016

Related U.S. Application Data

(63) Continuation of application No. 14/842,617, filed on Sep. 1, 2015.

(Continued)

(51) **Int. Cl.**

G04G 17/02 (2006.01)
G04G 21/02 (2010.01)

(Continued)

(52) **U.S. Cl.**

CPC ***G04G 17/02*** (2013.01); ***A61B 5/0205*** (2013.01); ***A61B 5/0261*** (2013.01); ***A61B 5/0295*** (2013.01); ***A61B 5/14551*** (2013.01); ***A61B 5/681*** (2013.01); ***G04B 39/02*** (2013.01); ***G04G 21/025*** (2013.01); ***G06F 1/163*** (2013.01);

(Continued)

(58) **Field of Classification Search**

None

See application file for complete search history.

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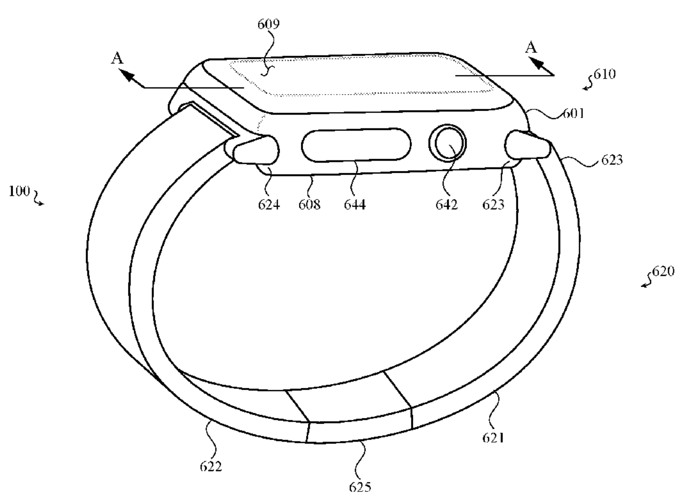
(57) **ABSTRACT**

A consumer product that is a portable and, in some cases, a wearable electronic device. The wearable electronic device may have functionalities including: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating with other electronic devices or services; visually depicting data on a display; gather data form one or more sensors that may be used to initiate, control, or modify operations of the device; determine a location of a touch on a surface of the device and/or an amount of force exerted on the device, and use either or both as input.

20 Claims, 26 Drawing Sheets



Related U.S. Application Data

(60) Provisional application No. 62/044,974, filed on Sep. 2, 2014.

(51) **Int. Cl.**

A61B 5/0295	(2006.01)
A61B 5/00	(2006.01)
A61B 5/0205	(2006.01)
A61B 5/026	(2006.01)
A61B 5/1455	(2006.01)
G06F 1/16	(2006.01)
G06F 3/01	(2006.01)
G04B 39/02	(2006.01)
A61B 5/024	(2006.01)
A61B 5/08	(2006.01)
G04B 3/04	(2006.01)
G04G 13/00	(2006.01)

(52) **U.S. Cl.**
CPC ***G06F 1/169*** (2013.01); ***G06F 1/1643*** (2013.01); ***G06F 3/015*** (2013.01); ***G06F 3/016*** (2013.01); *A61B 5/02427* (2013.01); *A61B 5/02438* (2013.01); *A61B 5/0816* (2013.01); *A61B 5/14552* (2013.01); *G04B 3/04* (2013.01); *G04G 13/00* (2013.01)

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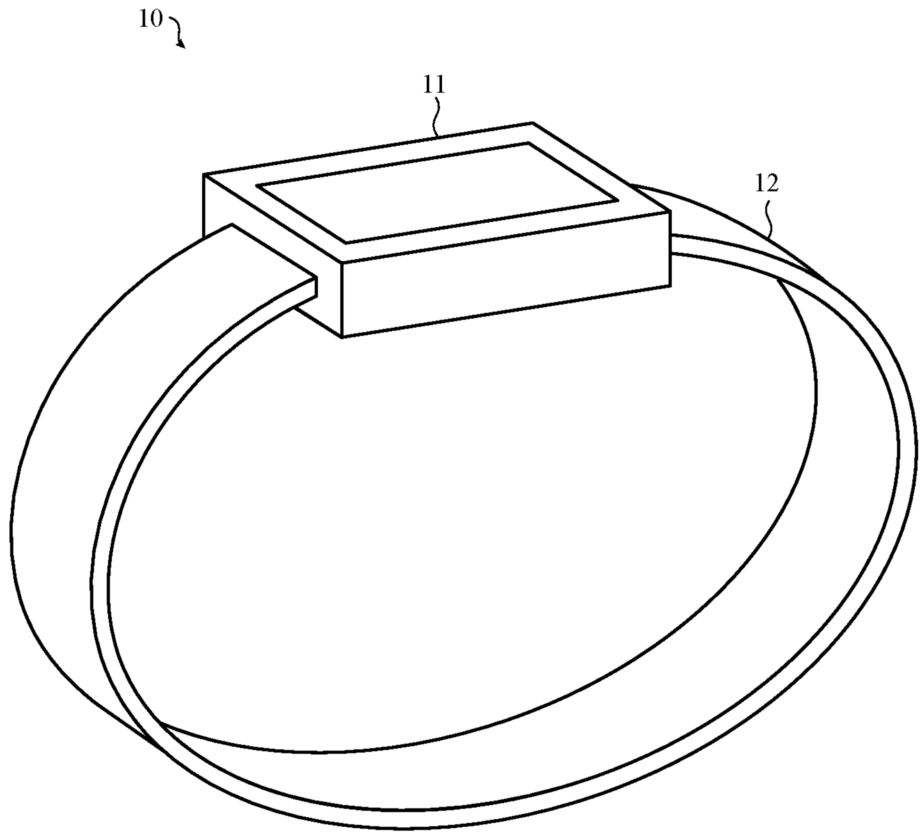
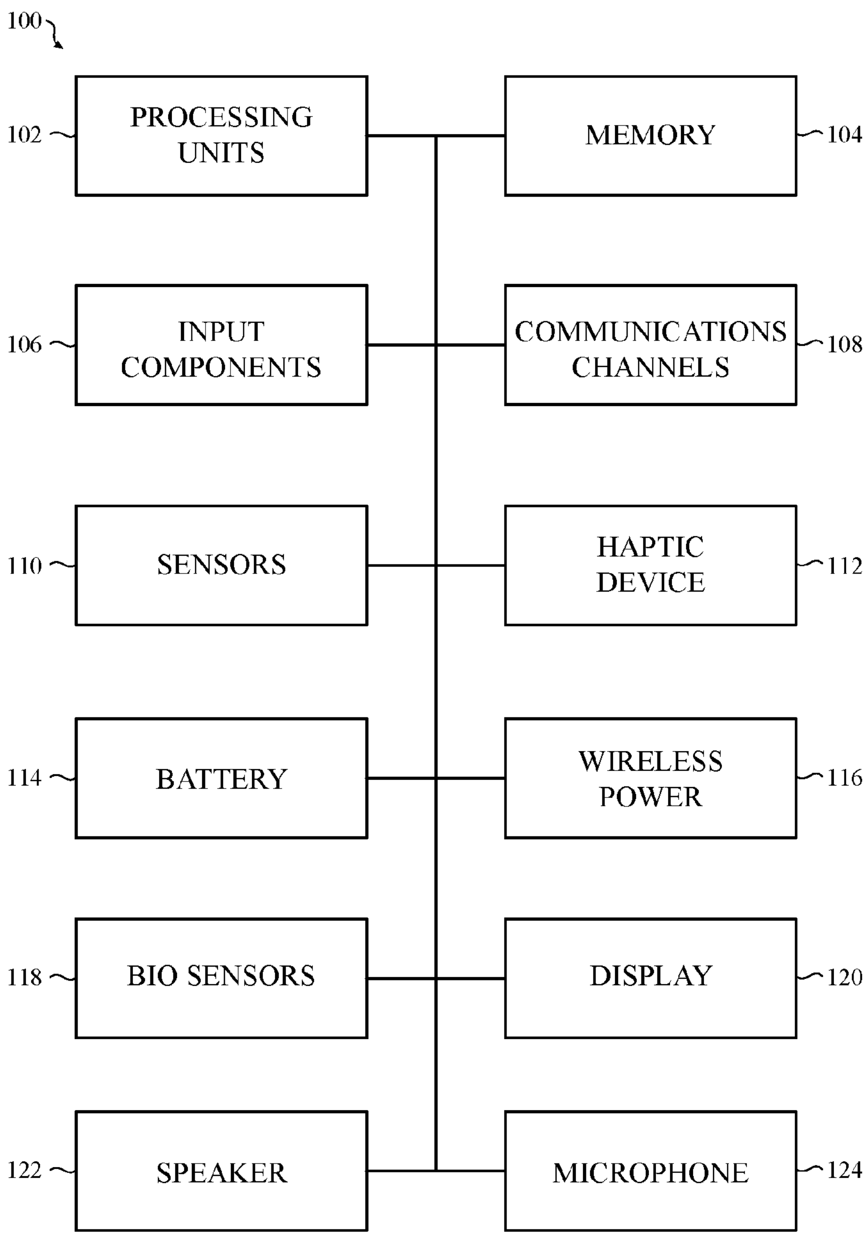


FIG. 1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INPUT COMPONENTS
COMMUNICATIONS CHANNELS
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SENSORS
HAPTIC DEVICE
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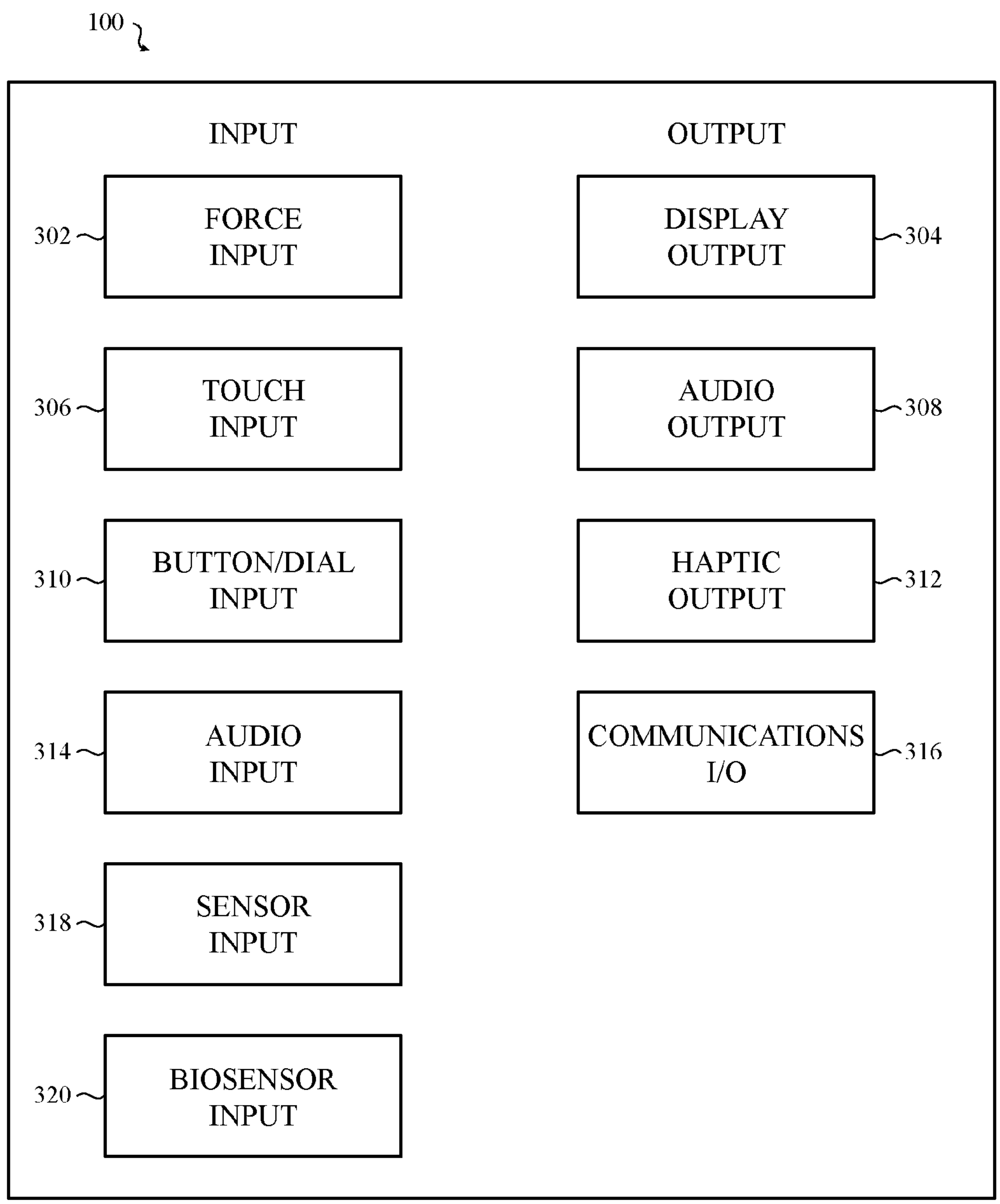
114
BATTERY
WIRELESS POWER
116
118
BIO SENSORS
DISPLAY
120
122
SPEAKER
MICROPHONE
124

FIG. 2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TOUCH INPUT
AUDIO OUTPUT
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BUTTON/DIAL INPUT
HAPTIC OUTPUT
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314
AUDIO INPUT
COMMUNICATIONS I/O
316
318
SENSOR INPUT
320
BIOSENSOR INPUT

FIG. 3

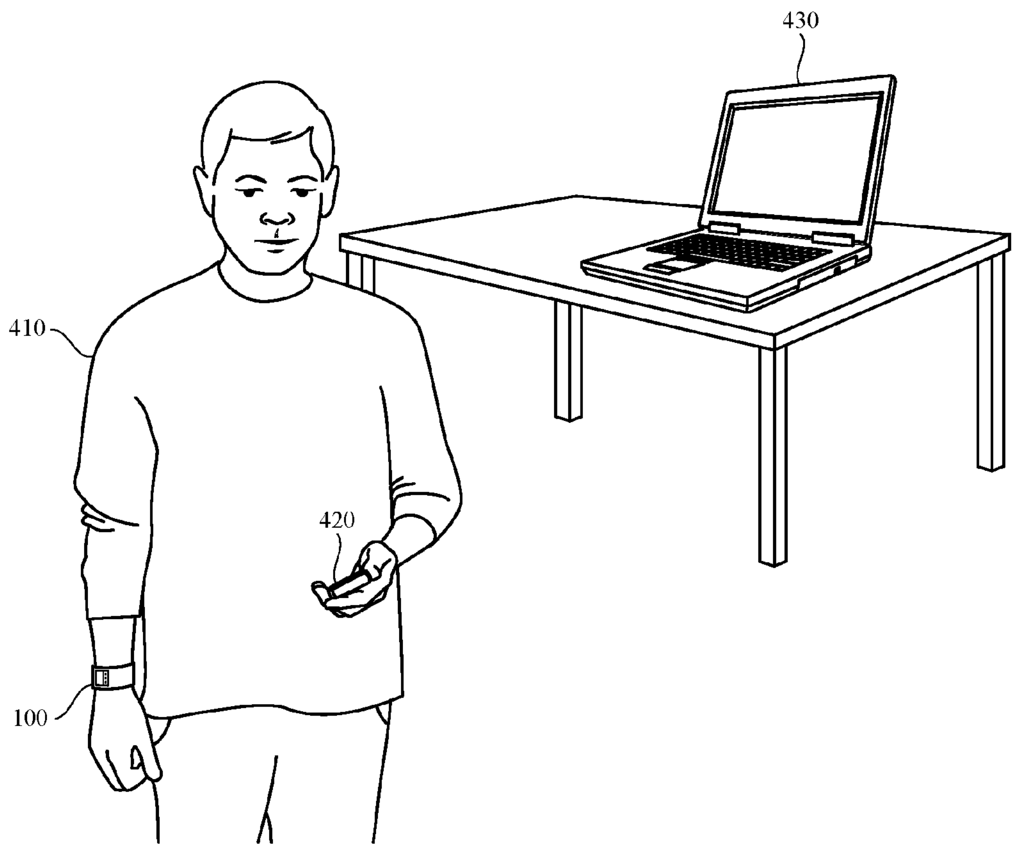

FIG. 4

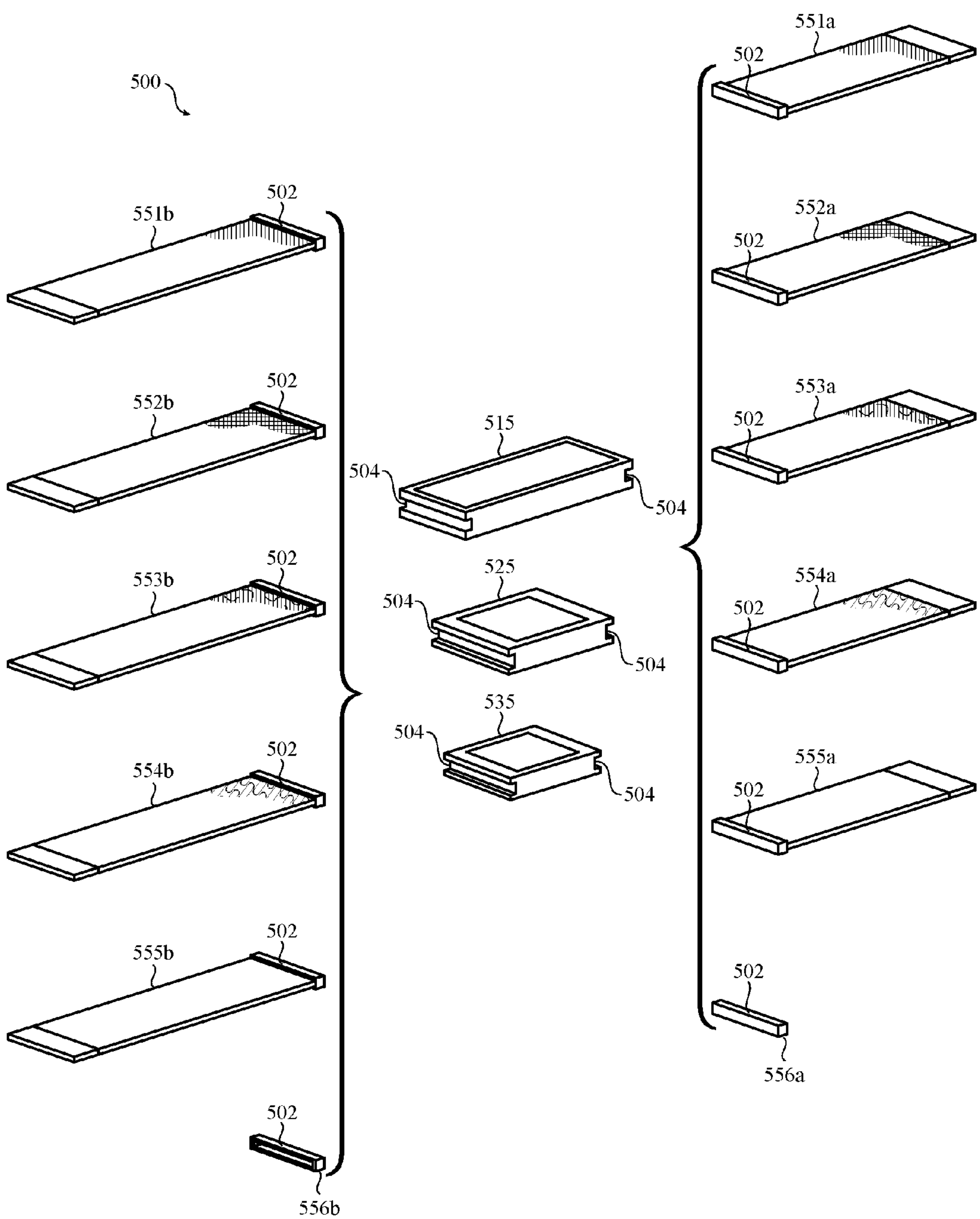
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FIG. 5

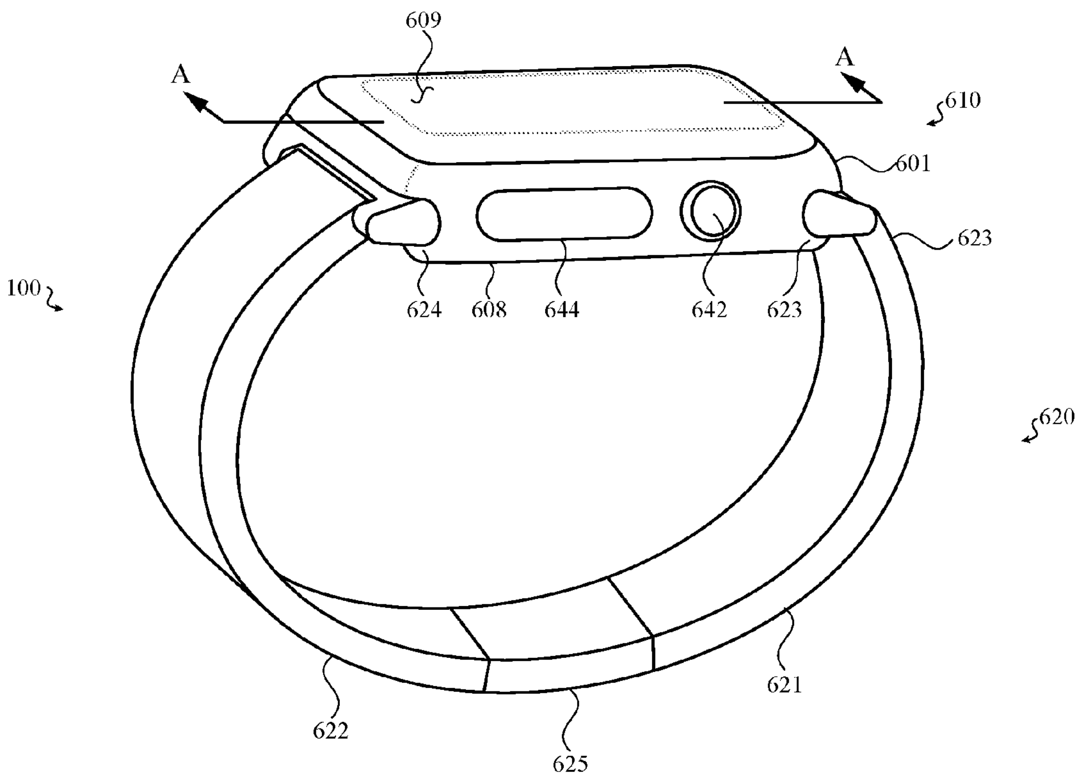


FIG. 6

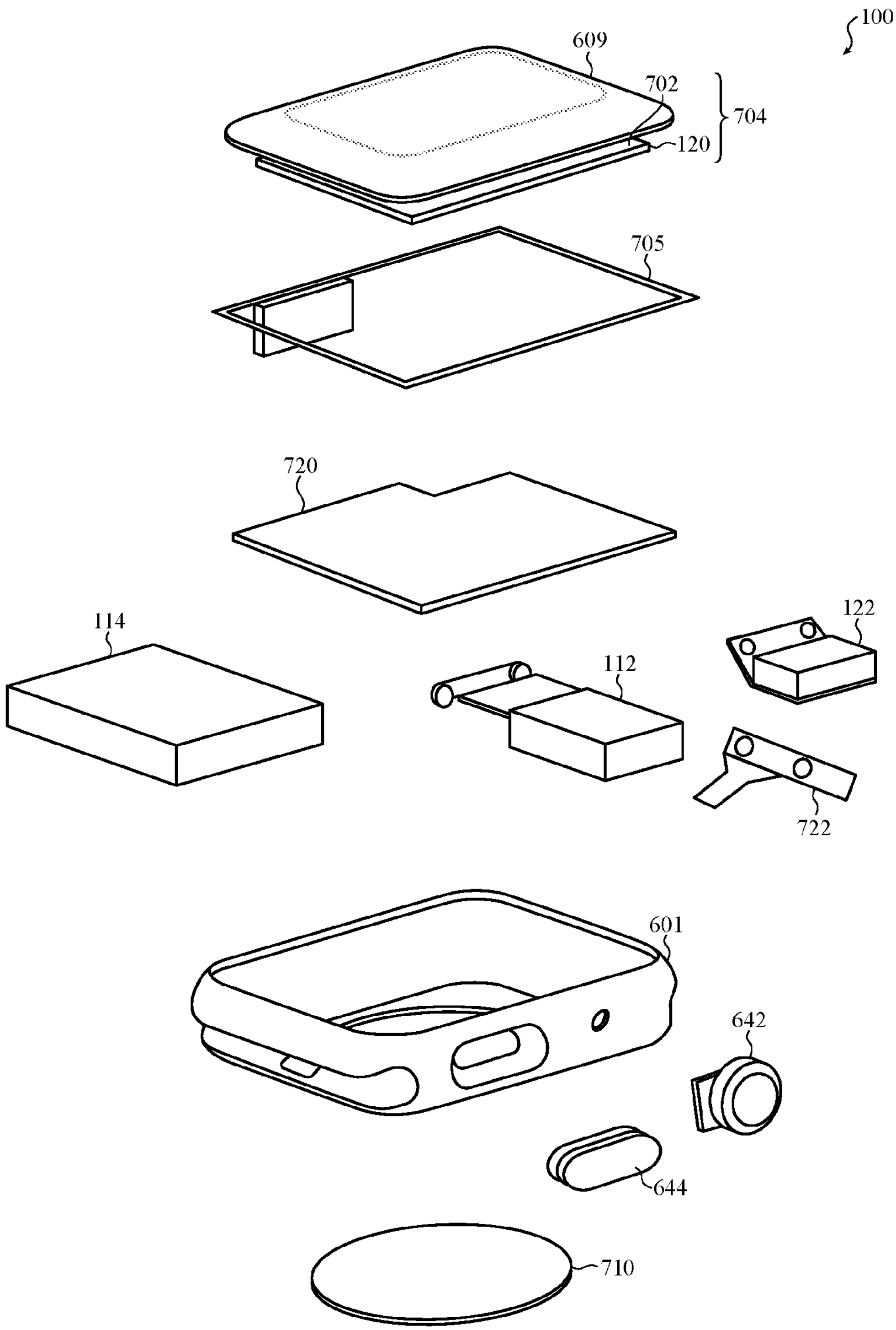
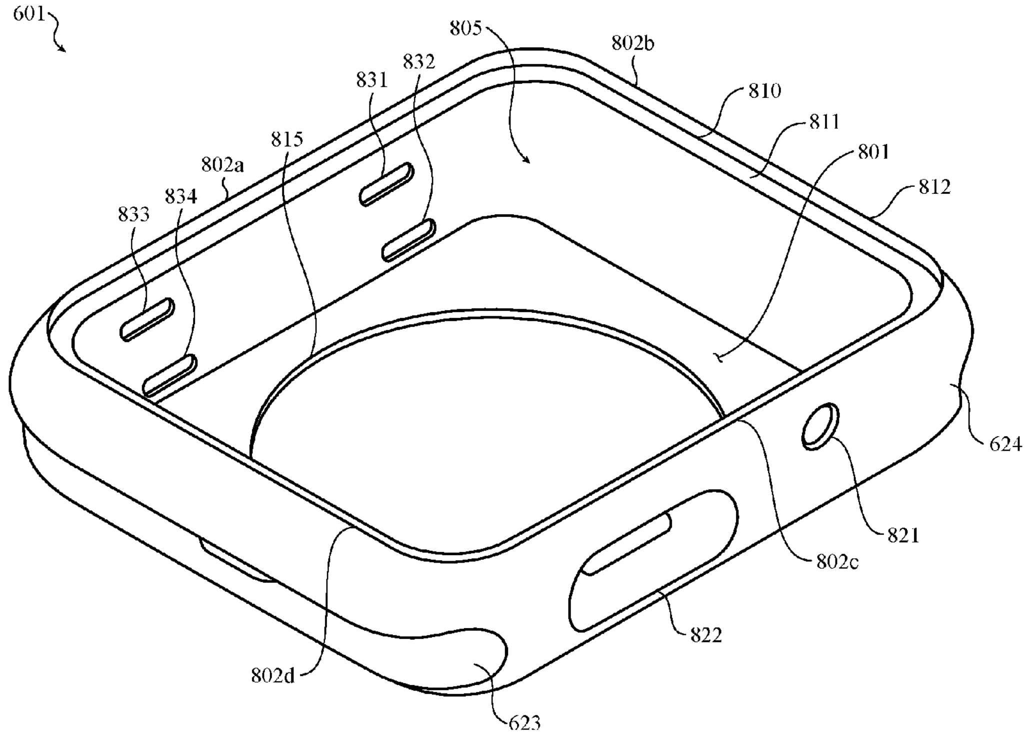


FIG. 7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623

FIG. 8

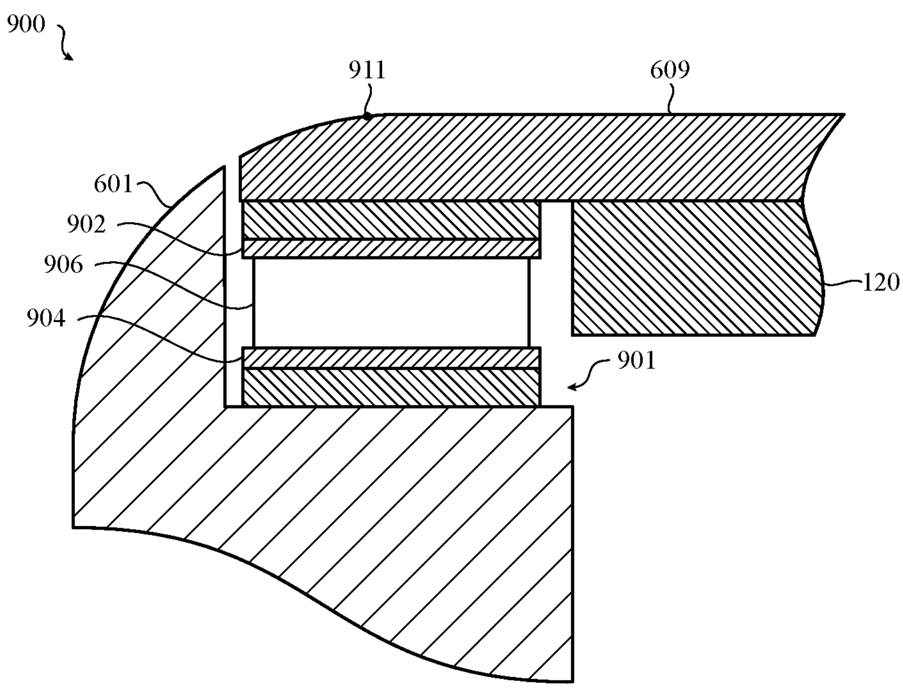


FIG. 9

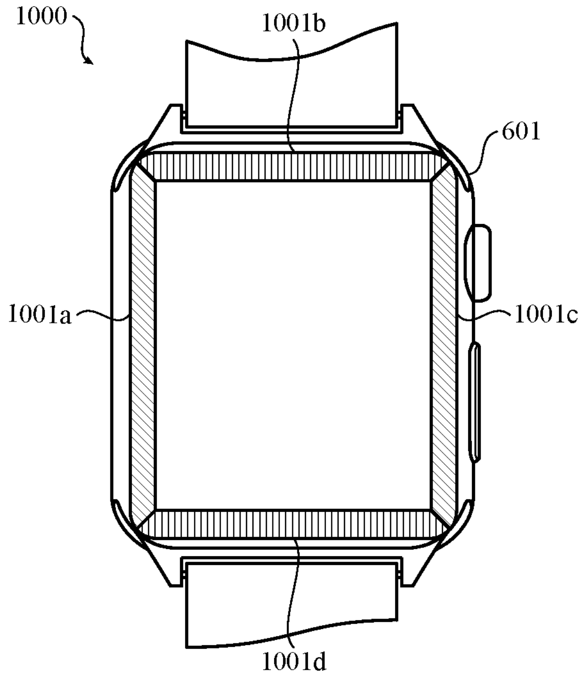


FIG. 10A

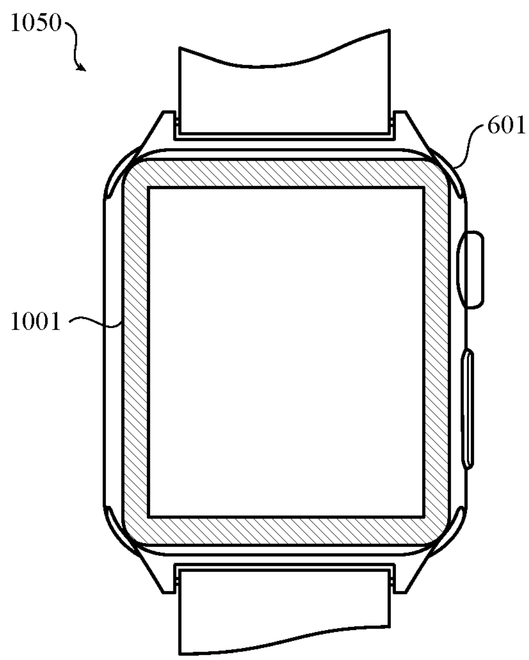


FIG. 10B

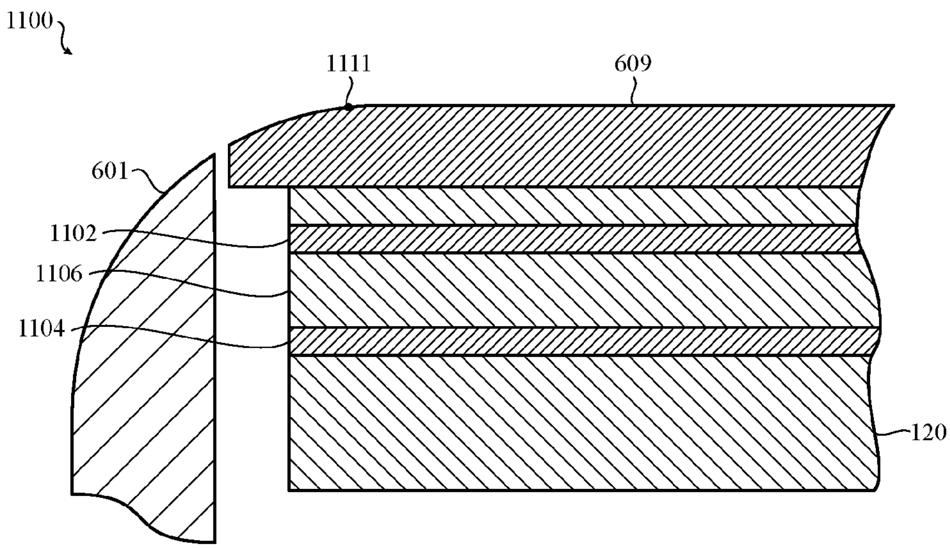


FIG. 11

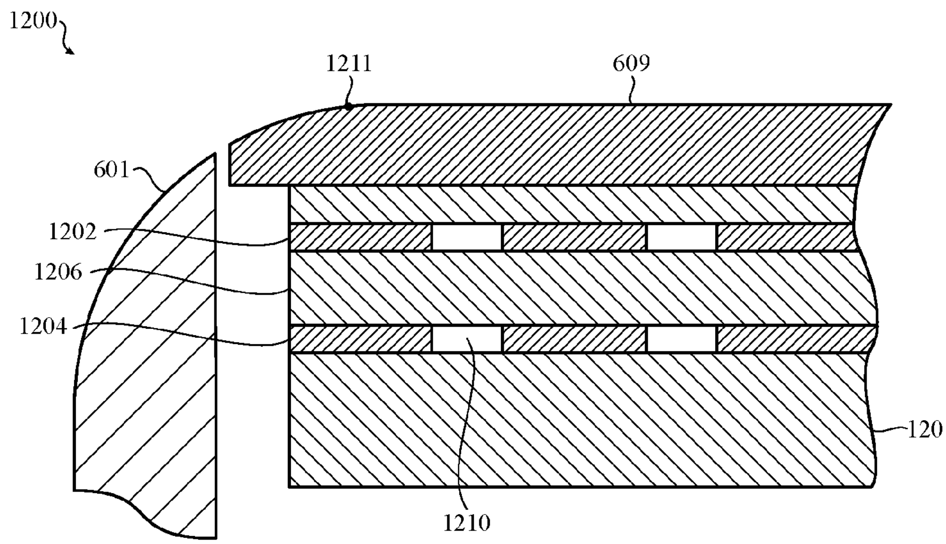


FIG. 12

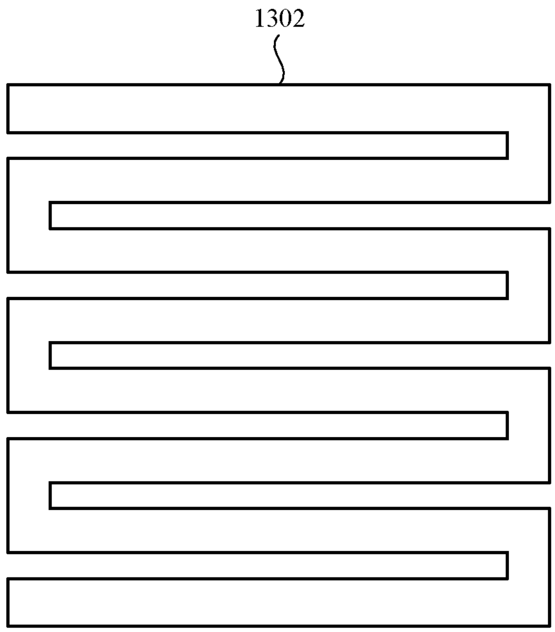


FIG. 13A

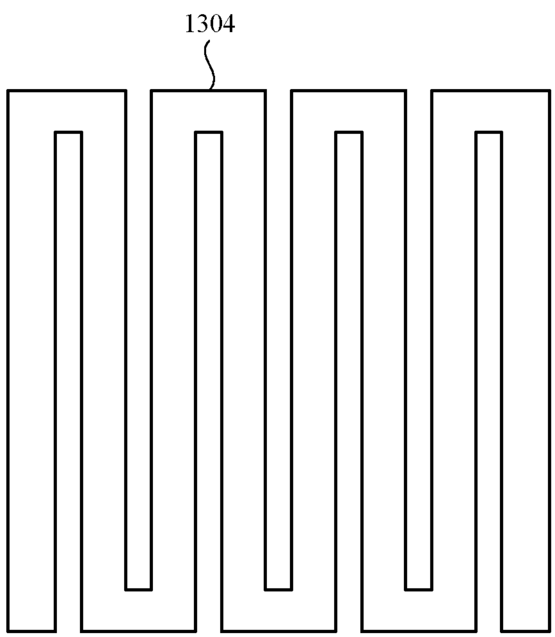


FIG. 13B

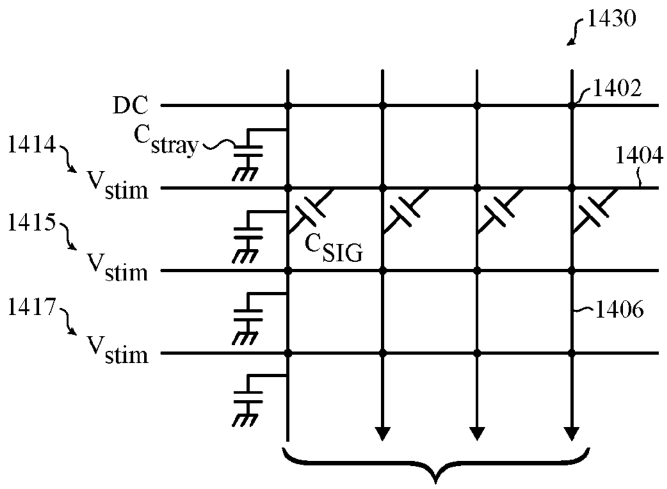


FIG. 14A

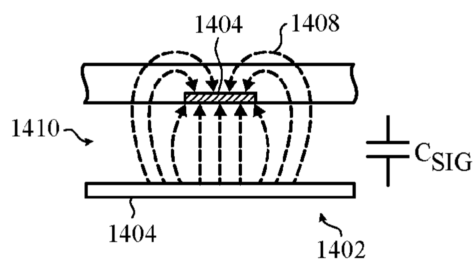


FIG. 14B

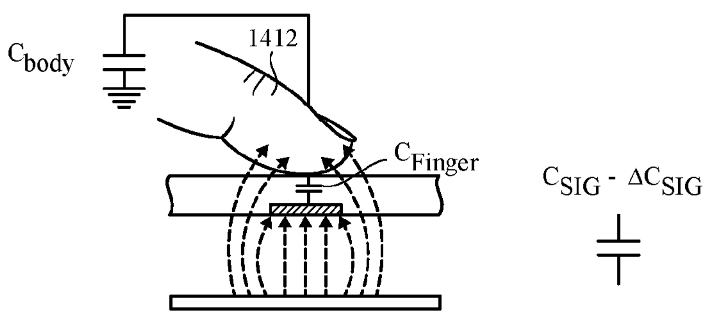


FIG. 14C

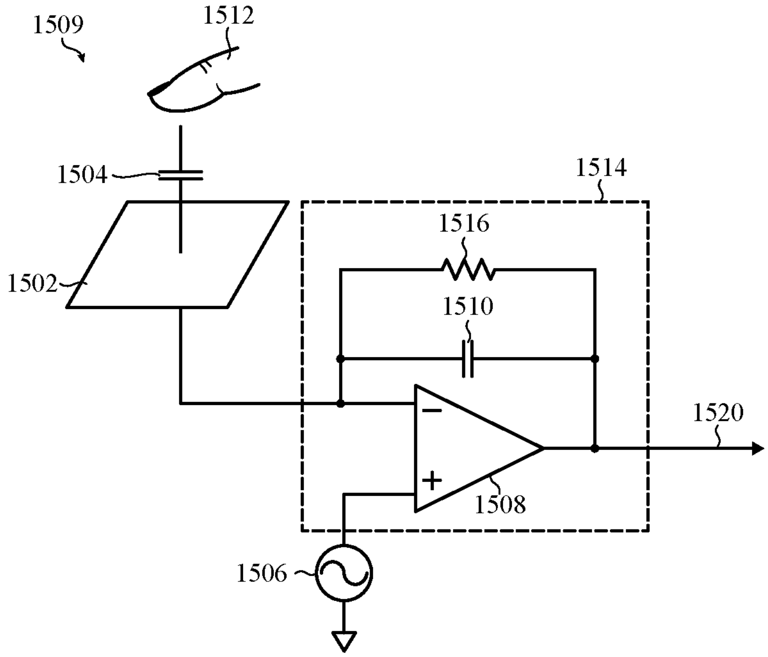


FIG. 15A

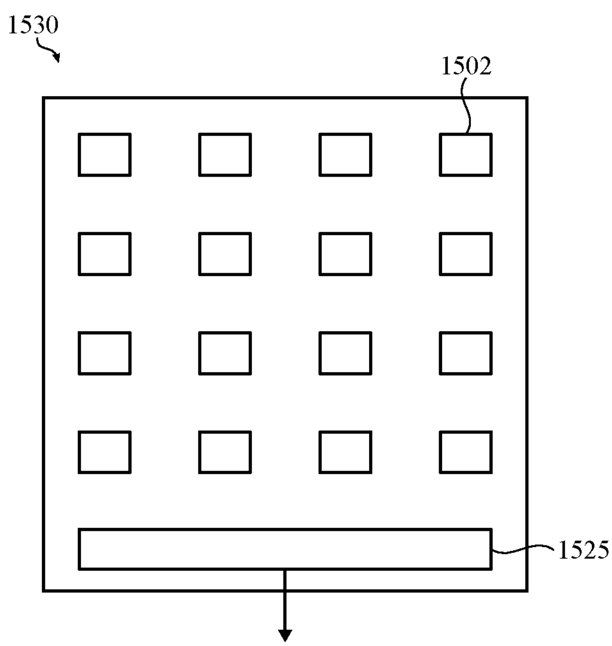


FIG. 15B

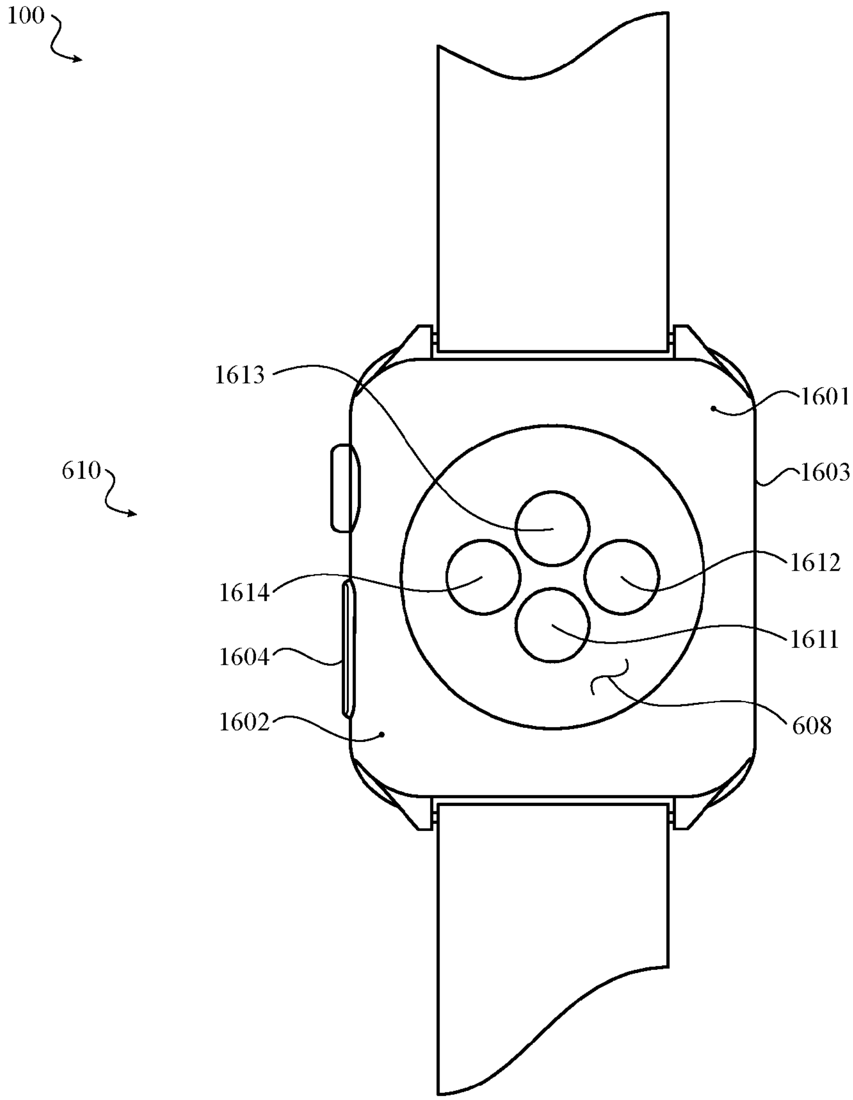


FIG. 16

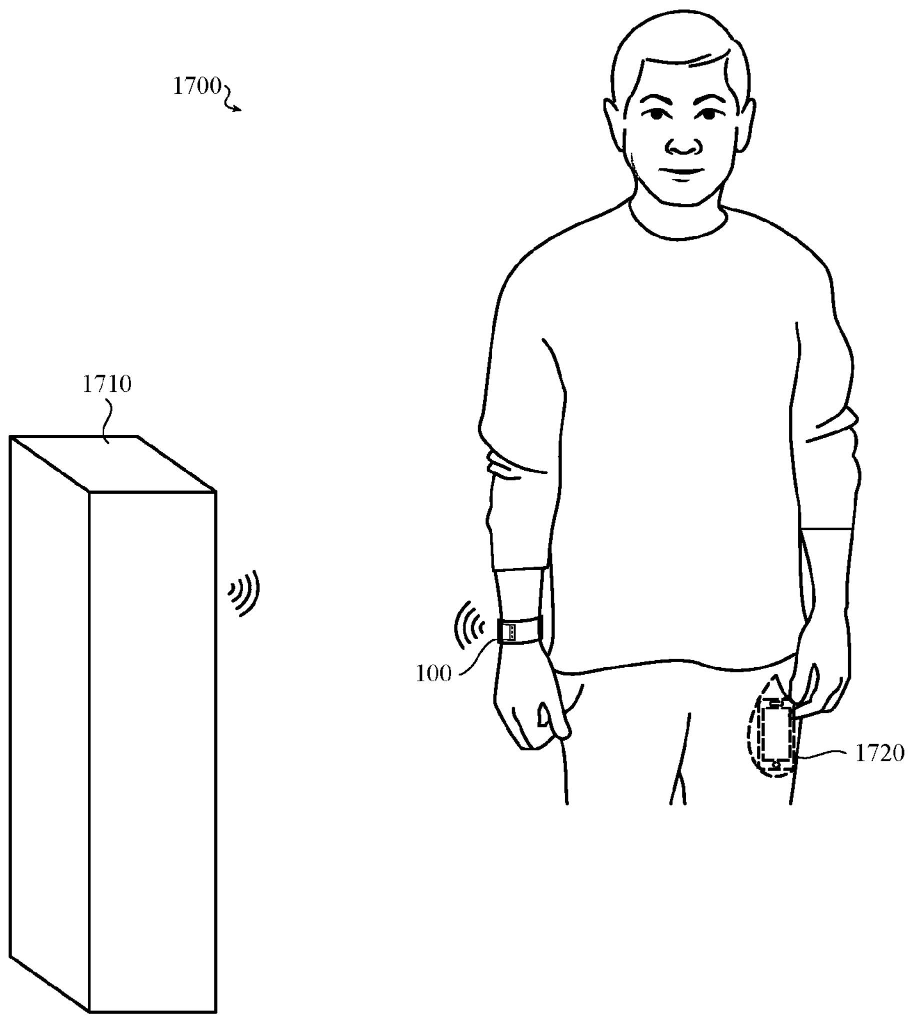


FIG. 17

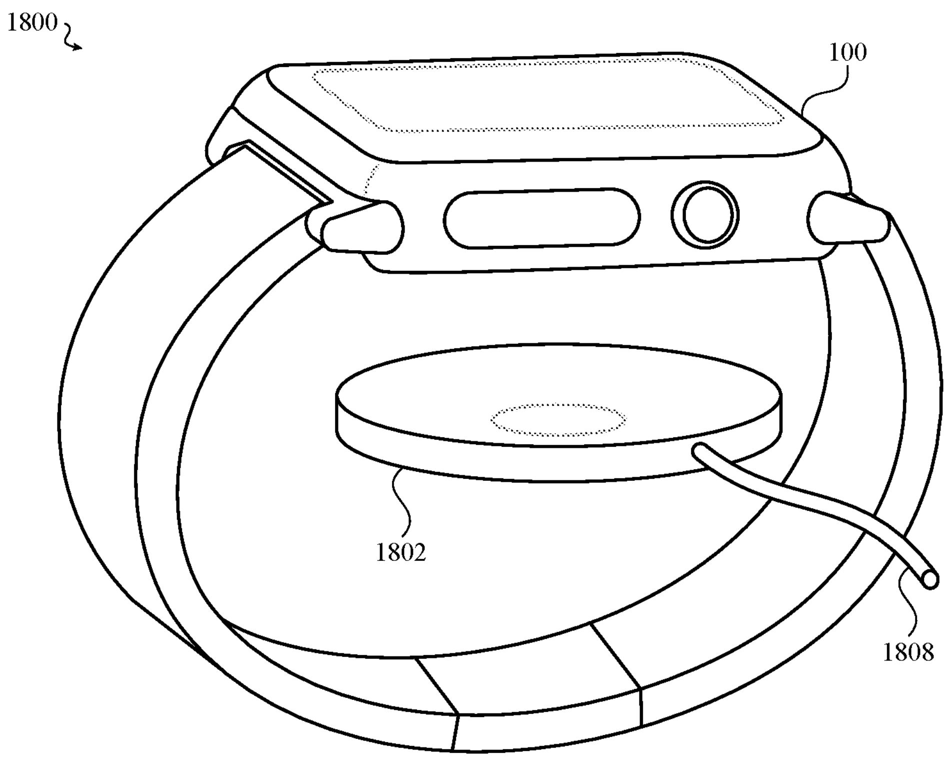
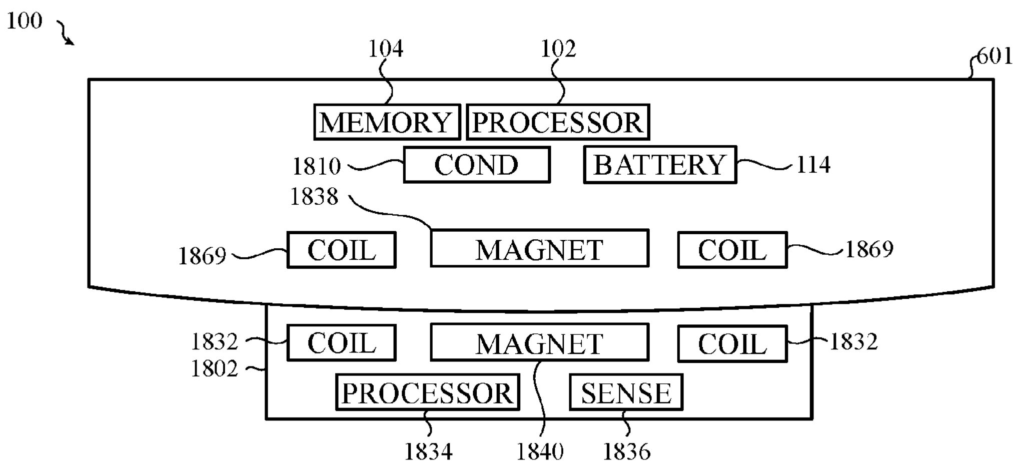


FIG. 18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PROCESSOR
SENSE
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1840
1836

FIG. 19

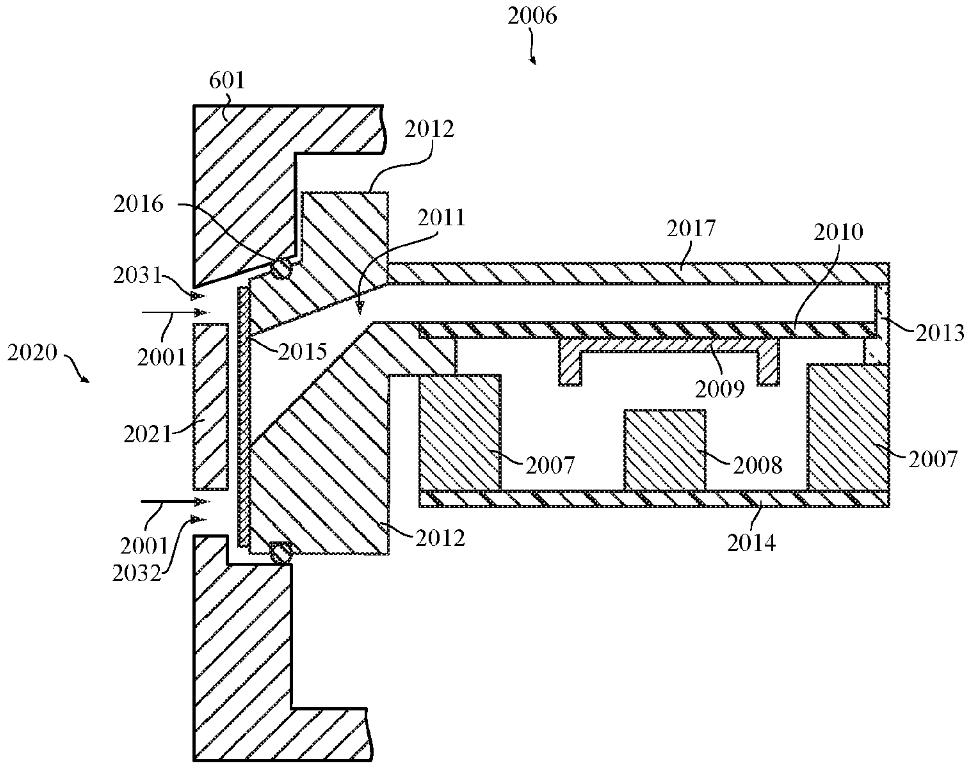
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FIG. 20

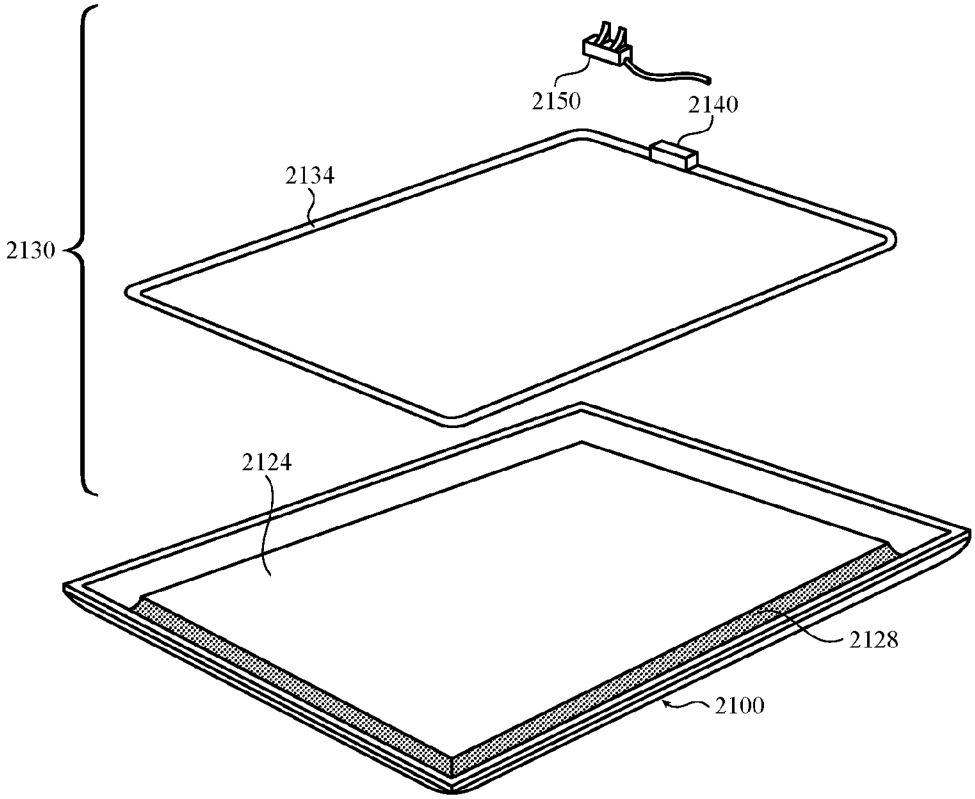

FIG. 21A

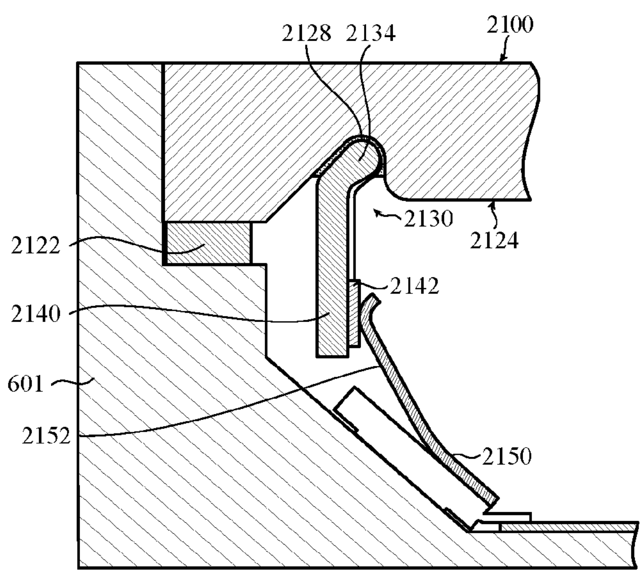

FIG. 21B

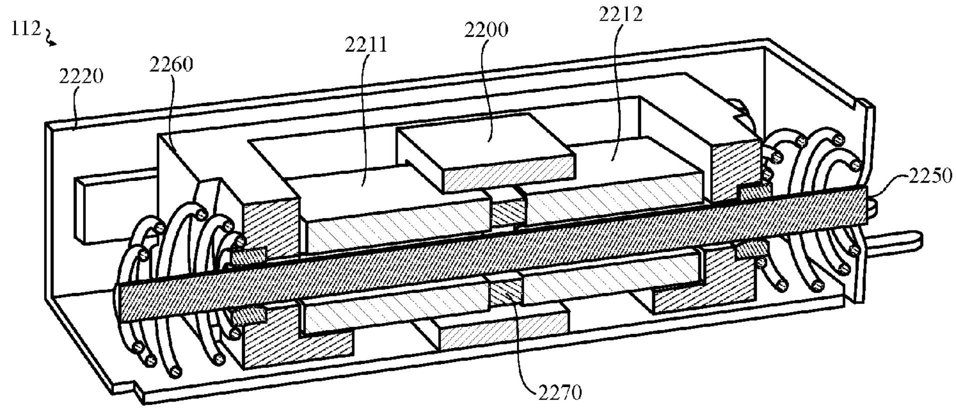

FIG. 22A

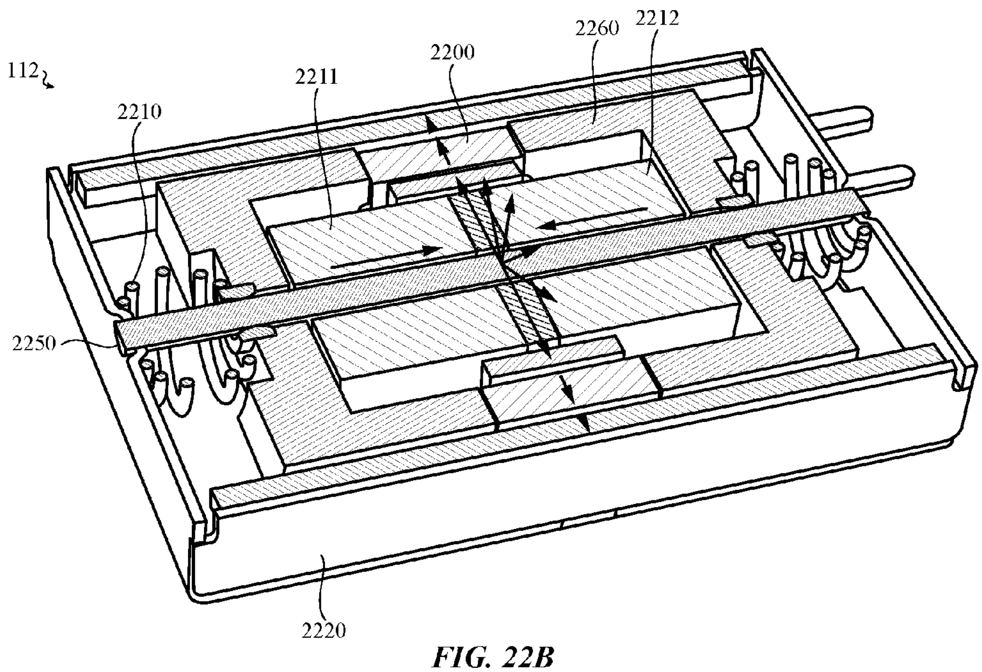

FIG. 22B

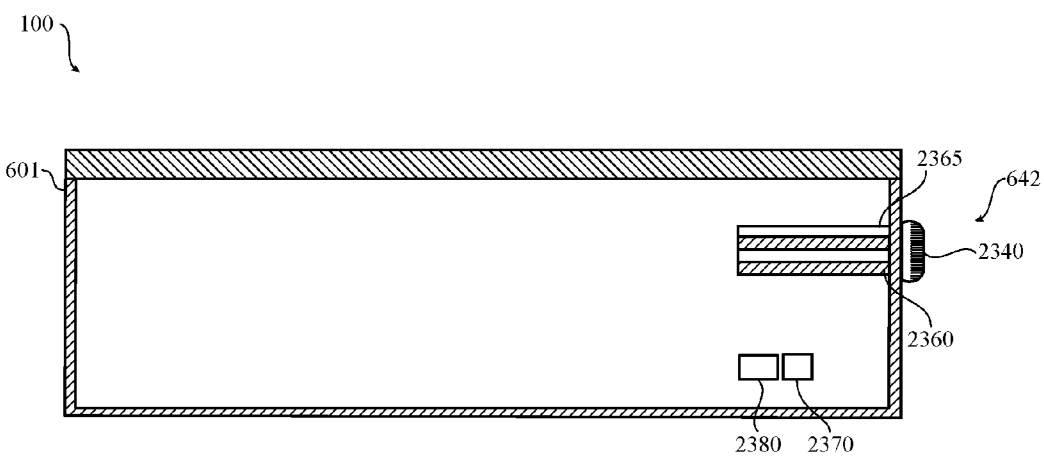

FIG. 23

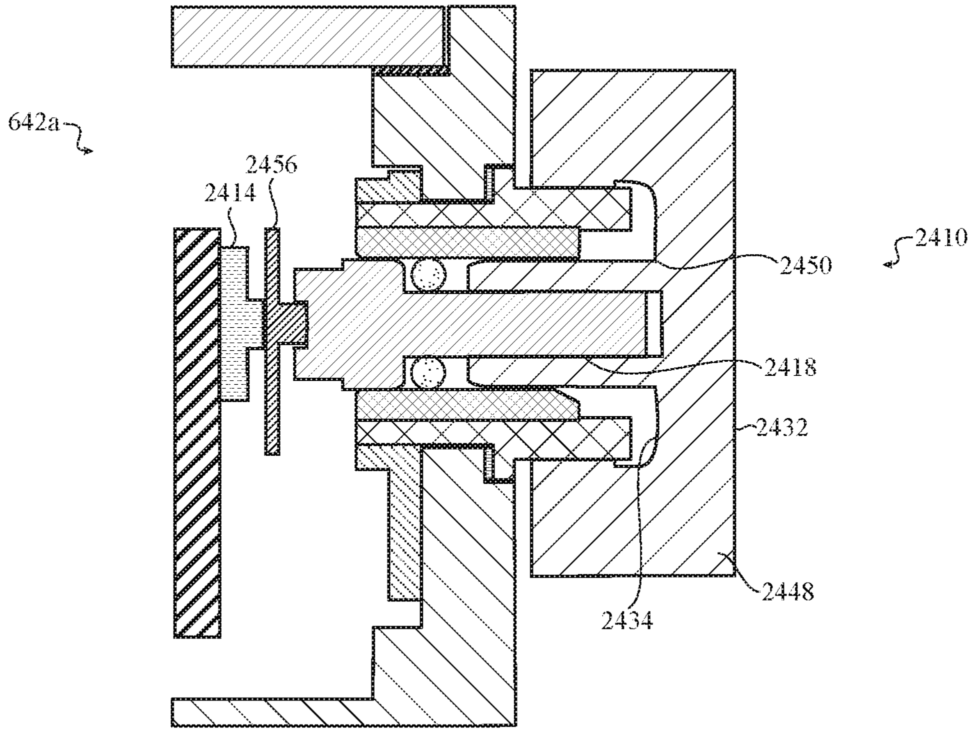

FIG. 24A

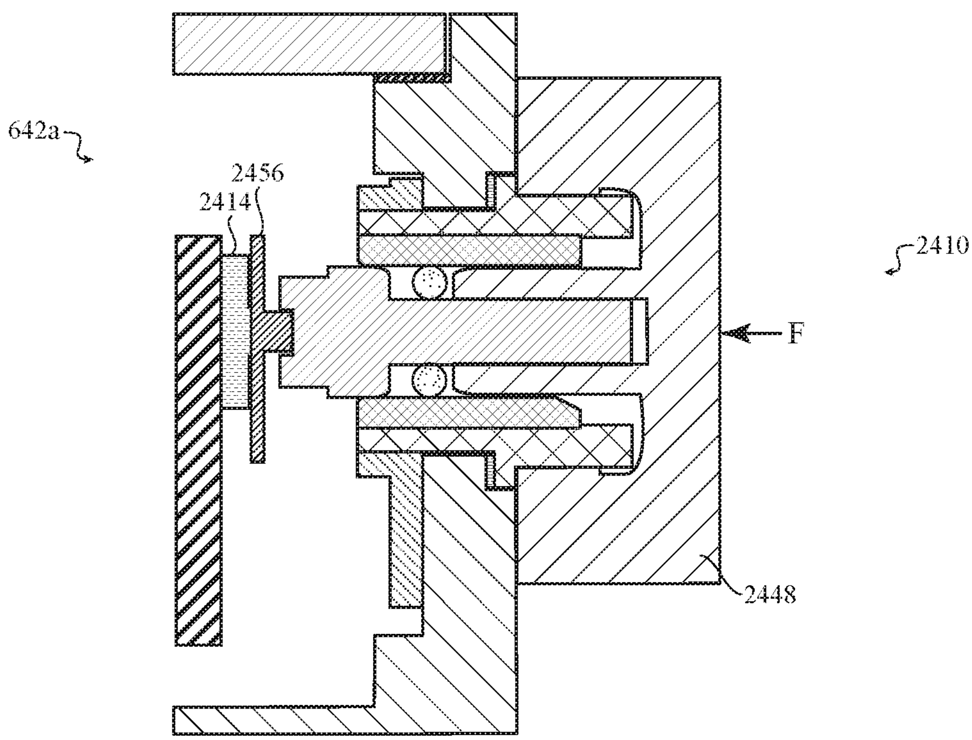

FIG. 24B

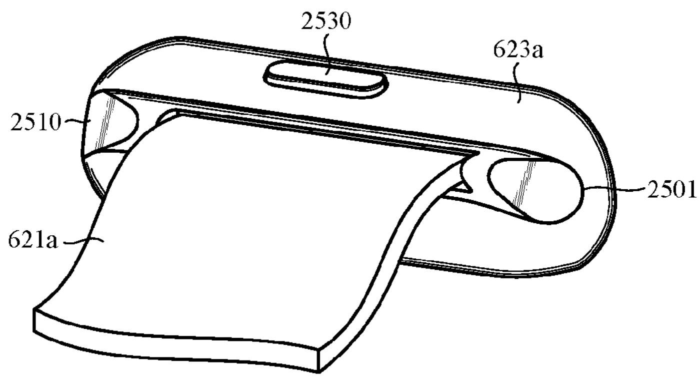

FIG. 25A

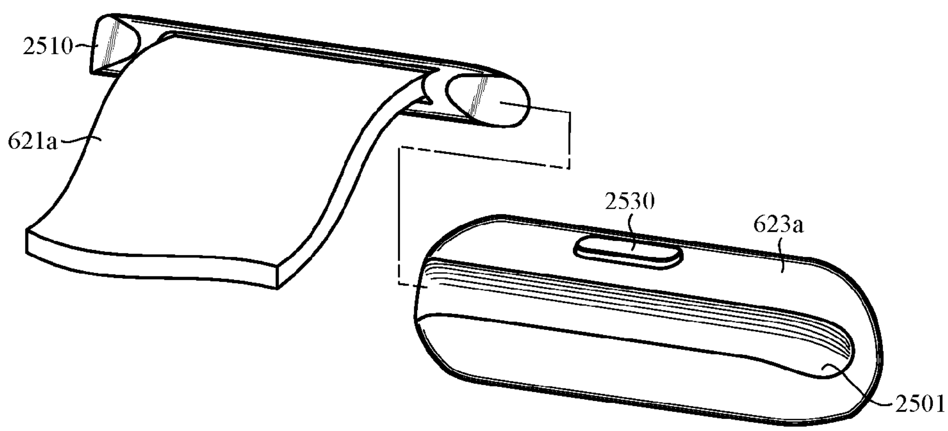

FIG. 25B

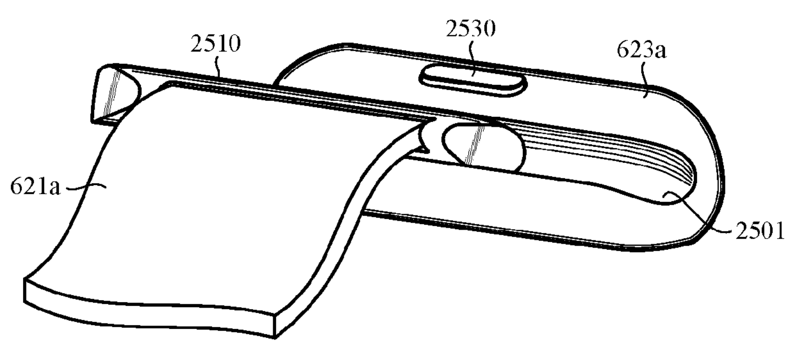

FIG. 25C

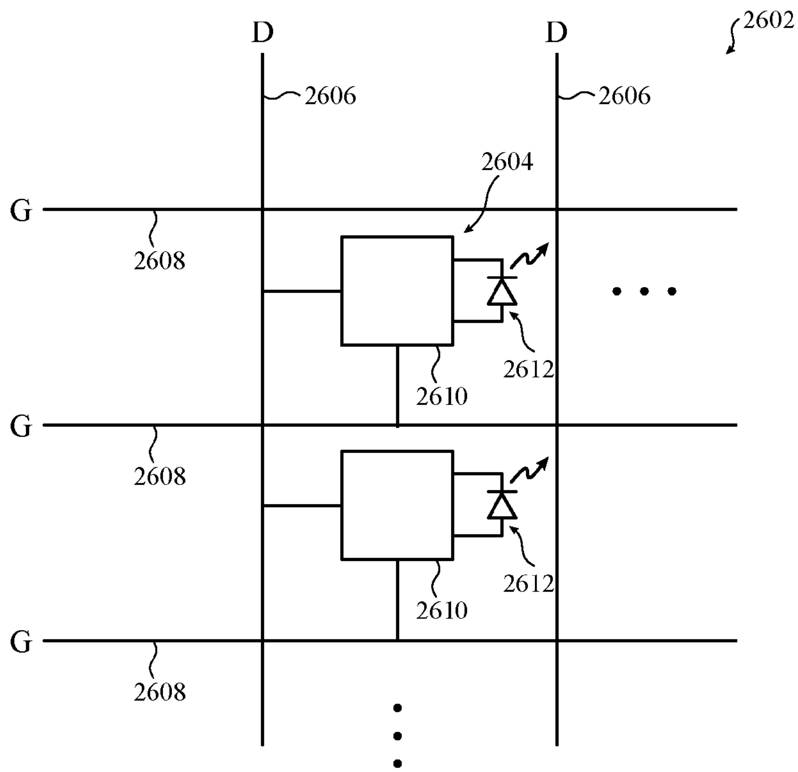

FIG. 26

WEARABLE ELECTRONIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation patent application of U.S. patent application Ser. No. 14/842,617, filed Sep. 1, 2015 and titled "Wearable Electronic Device," which is a nonprovisional patent application of and claims the benefit of U.S. Provisional Patent Application No. 62/044,974, filed Sep. 2, 2014 and titled "Wearable Electronic Device and Associated Methods of Use and Manufacture," the disclosures of which are hereby incorporated herein by reference in their entireties.

FIELD

The following disclosure generally relates to an electronic device, and more specifically to a wearable electronic device having a range of features, including touch input, force input, an interchangeable attachment system, health monitoring functionality, wireless power charging, wireless authentication and transaction functionality, and other features and functionality.

BACKGROUND

Portable electronic devices have become increasingly popular, and the features and functionality provided by portable electronic devices continue to expand to meet the needs and expectations of many consumers. However, some traditional portable electronic devices, particularly wearable electronic devices, may have relatively limited functionality or are only able to perform a specialized set of functions or tasks. For example, some traditional electronic wristwatches may be configured to perform a relatively limited set of functions, including displaying time, date, and performing basic timing functions. The embodiments described herein are directed to a wearable electronic device that provides a wide range of functionality, as compared to some traditional wearable electronic devices.

SUMMARY

The embodiments included herein are directed to a consumer product, which may include a portable or wearable electronic device that is configured to provide an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device.

Some example embodiments are directed to wearable electronic device having a housing that includes a flat bottom portion, a top portion defining a cavity, and a curved side portion that extends from the bottom portion to the top portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A display may be at least partially disposed within the cavity and may have a viewable area. The device may also include a cover disposed above the display and including a flat middle portion larger than the viewable area of the display, a curved edge portion surrounding the flat middle portion

and coinciding with the curved side portion along a perimeter of the cavity to form a continuous contoured surface.

In some embodiments, the continuous contoured surface is tangent with the flat bottom portion of the housing at a first end of the contour. The continuous contoured surface may also be tangent with the flat middle portion of the cover at a second end of the contour. In some embodiments, the continuous contoured surface has a constant radius.

In some embodiments, the cavity has a rectangular shape. The curved edge portion of the housing may have four sides that surround the cavity, each side is orthogonal to two adjacent sides. Each side may be connected to an adjacent side by a rounded corner. In some embodiments, the rounded corners have a curvature that corresponds to a curvature of the continuous contoured surface formed by the curved edge portion of the cover and the curved side portion of the housing.

Some embodiments include a crown module that is positioned at least partially within an aperture formed within the curved side portion of the housing. The crown module may include an outer surface configured to receive a rotary user input. The crown module may be offset with respect to a centerline of the housing between the top portion and the flat bottom portion. The offset may be toward the top portion of the housing. The crown module may include a dial having a portion that is higher than an interface between the cover and the housing.

In some example embodiments, a port is formed in the curved side portion of the housing. An acoustic module may be disposed within the housing and configured to produce an audio output through the port. The acoustic module may include an acoustic element and an acoustic cavity that acoustically couples the acoustic element to the port. The port may include an orifice that is offset with respect to the acoustic cavity to prevent the direct ingress of liquid into the acoustic module.

In some embodiments, the device includes a gasket positioned between the housing and the cover. The housing may also include a ledge formed along a perimeter of the cavity. The gasket may be positioned along the ledge that is formed along the perimeter of the cavity. The gasket, the cover, and the housing may be configured to cooperate to form a substantially water-proof seal.

In some example embodiments, the device includes a biosensor module that is disposed in an opening formed in the flat bottom portion of the housing. The biosensor module may include a chassis positioned in the opening of the housing and defining an array of windows. An array of light sources may be attached to the chassis and configured to emit light into the user through the array of windows. The biosensor module may also include an optically transparent rear cover disposed over the chassis and over the array of windows and operative to pass light emitted from the array of light sources into the user. In some embodiments, the rear cover has a convex outer contour.

Some example embodiments are directed to an electronic device having a housing comprising a bottom portion defining an opening and a band attached to the housing and configured to secure the electronic device to a user. A biosensor module may be disposed within the opening of the housing. A rear cover may be disposed over the biosensor module and may include an edge protruding outwardly from the bottom portion of the housing and an outer surface having a convex curved contour. In some embodiments, the outer surface of the rear cover defines one or more windows that provide operational access to one or more optical components of the biosensor module. The one or more

windows may have a curvature that matches the convex curved contour of the outer surface.

In some embodiments, the biosensor module includes an array of light sources that are configured to emit light into a body of the user. The biosensor module may also include a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. In some cases, the biosensor module is removably coupled to the housing.

In some embodiments, the device also includes a processing unit configured to compute a health metric associated with the user based on the sensor signal. The device may also include a display disposed within the housing and configured to display the health metric.

Some example embodiments are directed to a wearable electronic device, having a housing including a top portion, a cavity formed within the top portion, and a curved side portion that surrounds the cavity. The device may also include a transparent cover disposed over the cavity of the housing and may include a flat middle portion at a center of the transparent cover, a curved outer portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge of the transparent cover, and a mask positioned relative to an internal surface of the transparent cover. The mask may have an outer boundary located proximate to the edge of the transparent cover and an inner boundary located within the curved outer portion of the transparent cover.

In some embodiments, the device includes a display disposed below the transparent cover. A perimeter portion of a viewable area of the display may be disposed below the mask. The device may also include an antenna having a shape that corresponds to a shape of the cavity formed within the housing. The antenna may be disposed in a groove formed in the internal surface of the transparent cover. The groove may be formed between the outer boundary and the inner boundary of the mask. In some embodiments, the cover is formed from a sapphire material. The antenna may be configured to facilitate wireless communication between the wearable electronic device and an external device.

Some example embodiments are directed to an electronic device having a housing including a first end, a second end opposite the first end, a first side extending between the first and second ends, and a second side opposite to the first side and extending between the first and second ends. The first end may define a first groove extending between the first and second sides and may be configured to receive a first lug portion of a first band. The second end may define a second groove extending between the first and second sides and may be configured to receive a second lug portion of a second band. The first and second grooves may have an inwardly curved concave shape with an undercut feature that retains the first and second lug portions. In some embodiments, the first groove extends through a solid portion of the housing to form a continuous interior shape.

In some embodiments, the device includes a display at least partially disposed within a cavity of the housing. A cover may be disposed above the display and at least a portion of the first groove is disposed below the cover. The first and second grooves may be formed at an angle with respect to a centerline of the housing. The first and second grooves may be angled upward toward a top of the housing and inward toward the center of the housing. The first and second grooves may cross the centerline of the housing.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A crown may be disposed relative to the housing and configured to receive a rotational input. An encoder may be operatively coupled to the crown and configured to produce an encoder output that corresponds to the rotational input. A speaker module may be disposed within the housing and configured to produce an audio output that corresponds to the encoder output. A haptic device may be disposed within the housing and configured to produce a haptic output that corresponds to the encoder output. In some embodiments, the haptic output is synchronized with the audio output. The crown may be further configured to translate along an axis and actuate a tactile switch.

In some embodiments, the device also includes a display element within the housing. The device may be configured to display a list of items on the display element and scroll the list of items in response to the encoder output. The device may also be configured to synchronize the audio and haptic outputs with the scrolling of the list of items. In some embodiments, the crown is further configured to translate along an axis and actuate a tactile switch. The crown may be operative to select an item of the list of items when the tactile switch is actuated.

Some example embodiments are directed to a wearable electronic device having a housing that includes a bottom portion and an aperture formed in the bottom portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A biosensor module may be disposed in the aperture of the housing. The biosensor module may include an array of light sources configured to emit light into a body of the user, and a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. The device may also include a processing unit that is configured to compute a health metric associated with the user based on the sensor signal. A display may be disposed within the housing and configured to display the health metric.

In some embodiments, the array of light sources and the photodetector are configured to function as multiple photoplethysmography (PPG) sensors. Each PPG sensor may be configured to be used to compute a separate health metric. In some embodiments, a first light source of the array of light sources includes a green LED adapted to detect blood perfusion in the body. A second light source of the array of light sources may include an infrared LED adapted to detect water content of the body. The health metric may include one or more of: a heart rate, a respiration rate, a blood oxygenation level, and a blood volume estimate.

In some embodiments, the device also includes at least one pair of electrodes disposed on an exterior surface of the housing. The at least one pair of electrodes may be configured to produce a signal when the at least one pair of electrodes is in contact with the body. In some case, the signal is used to compute an additional health metric that includes one or more of: a heart function, a body fat estimate, and a body fat estimate.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. The device may also include an array of light emitting diodes (LEDs) disposed within the housing, the array of LEDs being configured to emit light. A photodetector may be disposed within the housing and configured to receive light produced by an LED of the array of LEDs that is reflected from a body of the user and produce a first sensor signal in response to the received light. The device

may also include at least one pair of electrodes disposed on an exterior surface of the wearable electronic device. The electrodes may be configured to produce a second sensor signal when the electrodes are in contact with a respective portion of the body. The device may also include a processing unit that is configured to compute one or more health metrics based on the first and second sensor signals. The device may also include a display disposed at least partially within the housing and configured to display the one or more health metrics.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be disposed relative to the housing and a display may be attached to a lower surface of the cover. A force sensor may be positioned between the cover and the housing and attaching the cover to the housing. The force sensor may be configured to detect the force of a touch on the cover. The force sensor may also form a barrier to prevent ingress of liquid into the wearable electronic device. In some embodiments, an antenna may be disposed relative to the cover and external from the housing. The antenna may be configured to facilitate wireless communication with an external device.

In some example embodiments, a wearable electronic device may include a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A display element may be positioned within the housing and a rechargeable battery may be disposed within the housing and operatively coupled to the display element. The device may also include a receive coil within the housing configured to inductively couple with an external transmit coil. A power conditioning circuit may be configured to recharge the rechargeable battery using power received by the receive coil. The power conditioning circuit may be configured to provide power to the display element. The device may also include a first alignment magnet positioned within the receive coil and configured to align the device with respect to a second alignment magnet positioned within the external transmit coil.

Some example embodiments are directed to a wearable electronic device that includes a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be positioned relative to the housing and a display may be disposed within the housing and below the cover. A force sensor may be disposed within the housing and configured to detect a force of a touch on the cover. A touch sensor may be disposed between the display and the cover. The touch sensor may be configured to detect a location of the touch on the cover. In some embodiments, the force sensor is disposed along a perimeter of the display. The device may also include a processing unit and memory disposed within the housing. The processing unit may be configured to interpret a touch gesture on a surface of the cover using a force output from the force sensor and a touch output from the touch sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements.

FIG. **1** depicts an example wearable electronic device having a device body and band.

FIG. **2** depicts an example schematic diagram of a wearable electronic device.

FIG. **3** depicts an example functional diagram for a wearable electronic device.

FIG. **4** depicts an example wearable electronic device as part of a system of devices.

FIG. **5** depicts a system of interchangeable components for a wearable device.

FIG. **6** depicts an example wearable electronic device having a device body and band.

FIG. **7** depicts an exploded view of components of an example wearable electronic device.

FIG. **8** depicts an example housing for a wearable electronic device.

FIG. **9** depicts an example force sensor configured to use a capacitive measurement.

FIGS. **10**A-B depict plan views of example force sensors.

FIG. **11** depicts an example force sensor configured to use a resistive measurement.

FIG. **12** depicts an example pixelated force sensor configured to use a resistive measurement.

FIGS. **13**A-B depict example force sensor structures.

FIGS. **14**A-C depict an example touch sensor based on mutual capacitance.

FIGS. **15**A-B depict an example touch sensor based on self capacitance.

FIG. **16** depicts an example device having biosensors.

FIG. **17** depicts an example device having wireless communications with an external device.

FIG. **18** depicts an example electronic device and example dock of an inductive charging system.

FIG. **19** depicts a block diagram of an example inductive charging system.

FIG. **20** depicts an example acoustic module.

FIGS. **21**A-B depict an example cover and antenna.

FIGS. **22**A-B depict an example haptic module.

FIG. **23** depicts an example device having a crown module with an encoder.

FIGS. **24**A-B depict an example device having a crown module with a tactile switch.

FIGS. **25**A-C depict an example receiving feature for a band.

FIG. **26** depicts example elements of a display.

DETAILED DESCRIPTION

Provided herein are descriptions and examples of a consumer product, which may include a portable electronic device, a wearable electronic device, or other type of device. By way of example and not by way of limitation, the consumer product may be an electronic device, a mechanical device, or an electromechanical device. Specific example devices include mobile phones, personal digital assistants, music players, timekeeping devices, health monitoring devices, tablet computers, laptop computers, glasses (electronic or otherwise), portable storage devices, and the like.

In one particular embodiment, the consumer product is a portable and, more specifically, a wearable consumer product. A wearable consumer product is one that can be worn by or otherwise secured to a user. For example, the consumer product may be a wearable electronic device including, but not limited to, a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and the like. A wearable consumer product may be worn by a user in a variety of ways. In some examples, the consumer product is a wrist-worn product and may include a band that can be wrapped around a user's wrist to secure the consumer product to the user's body. The device may include one or more other types

of attachments including, for example, an armband, lanyard, waistband, chest strap, and the like.

Some aspects of the disclosure are directed to a wearable electronic device having improved functionality and/or versatility as compared to some traditional wearable devices. For example, some aspects of the disclosure are directed to a consumer product, such as a portable electronic device, having an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device. Some aspects of the following disclosure are directed to the integration of a variety of subsystems or modules to provide functionality that may not be possible using some traditional device platforms. In some cases, the configuration and/or functionality provided by the various subsystems may be configurable by the end user, the manufacturer, and/or a vendor of the device. Example subsystems or modules of a consumer product and their respective functions are described below with respect to FIGS. **2** and **3**.

Some aspects of the disclosure are directed to a consumer product that is configured to communicate wirelessly with any of a number of other devices, such as a mobile phone, computer, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Through wireless communication with other devices, the consumer product may transmit and/or receive various notifications, messages, or other information between devices. The wireless communication may also facilitate the relay of alerts or other device outputs to notify the user of an event or action. In some aspects, the consumer product may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. An example communication system is described below with respect to FIG. **4** and with respect to other examples provided herein.

In some aspects, the consumer product may include a system of interchangeable components used to attach or secure the consumer product to the user. The system of interchangeable components may include a set of interchangeable bands or attachment devices that are configured to connect or attach to a receiving feature on the body of the product. The receiving feature may be standardized within the system of interchangeable components and allow multiple types of bands or attachment devices to be used with the same housing or body. The system of interchangeable components may also allow for an interchange between different bodies, which may include different types of electronic devices or other consumer products. Each body of the different devices or products may have a similar receiving feature that is standardized within the system of interchangeable components. An example system of interchangeable components is described below with respect to FIG. **5** and with respect to other examples provided herein.

Some aspects of the present disclosure are directed to a consumer product that includes a body that includes a case or housing used to protect as well as support the internal components of the product in their assembled position. The housing may enclose and support various components, including, for example, integrated circuits, subsystems, modules, and other internal components of the device. In some aspects, the housing forms a water-resistant or waterproof barrier and also provides structural rigidity necessary to protect internal components. The housing may be formed as a single piece, which may enhance the structural rigidity, water impermeability, and manufacturability of the housing. An example housing and example internal components for a consumer product are provided below with respect to FIGS. **6-8** and with respect to other examples provided herein.

In some aspects, the consumer product includes a force sensor that is configured to detect and measure the magnitude of a force or pressure on a surface of the product. In some implementations, the force sensor includes a capacitive-based sensor that is configured to estimate the force based on a deflection or movement between capacitive plates that is caused by and correlates to the amount of force caused by a touch. In some implementations, the force sensor is a resistance- or charge-based sensor that is configured to estimate the force based on the deflection of a sheet or film that is positioned relative to the touch-sensitive surface of the product. In some implementations, the output from the force sensor is combined with the output from a touch sensor, which may be self-capacitive or mutually capacitive, or a combination of the two. Example force and touch sensors are described below with respect to FIGS. **9-15**B and with respect to other examples provided herein.

In some aspects, the consumer product includes one or more biosensors. The biosensors may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. Example health metrics include, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. In some embodiments, the biosensors include an electrical sensor that may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. An example consumer product having multiple biosensors is described below with respect to FIG. **16** and with respect to other examples herein.

In some aspects, the consumer product is configured to perform wireless communication with an external device. In some implementations, the wireless communication may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce. An example consumer product having wireless communications with an external device is described in more detail below with respect to FIG. **17** and with respect to other examples herein.

In some aspects, the consumer product is configured to recharge an internal battery using a wireless charging system. In some implementations, the consumer product includes one or more receiving inductive coils that are configured to cooperate with one or more transmitting inductive coils that are located in a charging dock or other external device. The wireless charging system may allow the transfer of power and/or wireless communications with the consumer product without the use of an external port or terminal connection. An example consumer product having wireless charging capabilities is described in more detail below with respect to FIGS. **18-19** and with respect to other examples herein.

In some aspects, the consumer product includes one or more acoustic modules that are configured to function as a speaker and/or a microphone for the product. The speaker and/or microphone may include features that enhance the water/liquid resistance or impermeability of the consumer

product. The consumer product may also include a haptic module or actuator that is configured to produce a haptic output that may be perceived by the user. In some implementations, the output of an acoustic module, such as a speaker, and the haptic module may be used to provide feedback or an alert to the user. In some cases, an acoustic module and the haptic module provide feedback to the user and may be coordinated with a user input, such as user-interface selecting, user-interface scrolling, or other user input command. An example acoustic module is described below with respect to FIG. **20** and an example haptic module is described below with respect to FIGS. **22**A-B.

In some aspects, the consumer product includes a dial or crown that is coupled to an encoder or other rotary sensor for detecting a rotary input. In some implementations, the output from the optical encoder is used to drive an aspect of a user interface or control other functionality of the product. Additionally, the dial or crown may include a tactile switch that can be actuated by pressing inward on the dial or crown. An example consumer product having a crown is described below with respect to FIGS. **23**-**24**B and with respect to other examples herein.

The description that follows includes sample devices, components, modules, systems, methods, and apparatuses that embody various elements of the present disclosure. However, it should be understood that various elements of the described disclosure may be combined and/or practiced in a variety of forms in addition to those described herein. In particular, the modules and components are described in a particular combination with respect to some examples provided below. However other combinations are possible, which may be achieved by adding, removing, and/or re-arranging modules to obtain a device or system having the desired characteristics.

FIG. **1** depicts a wearable consumer product **10**. For example, the consumer product **10** may be a wearable electronic device. In one example, the consumer product **10** may be a wearable multifunctional electronic device including multiple functionalities such as time keeping, health monitoring, sports monitoring, medical monitoring, communications, navigation, computing operations, and/or the like. The functionalities may include but are not limited to: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating (in a wired or wireless fashion) with other electronic devices or services, which may be different types of devices having different functionalities; providing alerts to a user, which may include audio, haptic, visual and/or other sensory output, any or all of which may be synchronized with one another; visually depicting data on a display; gathering data form one or more sensors that may be used to initiate, control, or modify operations of the device; determining a location of a touch on a surface of the device and/or an amount of force exerted on the device, and using either or both as input; accepting voice input to control one or more functions; accepting tactile input to control one or more functions; capturing and transmitting images; and so on. These and other functions and features will be described in more detail herein.

The wearable consumer product **10** can take a variety of forms. In one example, the consumer product **10** may be a wrist-worn electronic device. The device may include a variety of types of form factors including, wristbands, armbands, bracelets, jewelry, and/or the like.

In the illustrated embodiment, the consumer product **10** includes a device body **11**. The device body **11** may include a housing that carries, encloses and supports both externally and internally various components (including, for example. integrated circuit chips and other circuitry) to provide computing and functional operations for the consumer product **10**. The components may be disposed on the outside of the housing, partially within the housing, through the housing, completely inside the housing, and the like. The housing may, for example, include a cavity for retaining components internally, holes or windows for providing access to internal components, and various features for attaching other components. The housing may also be configured to form a water-resistant or water-proof enclosure for the body **11**. For example, the housing may be formed from as a single unitary body and the openings in the unitary body may be configured to cooperate with other components to form a water-resistant or water-proof barrier.

Examples of components that may be contained in the device body **11** include processing units, memory, display, sensors, biosensors, speakers, microphones, haptic actuators, batteries, and so on. In some cases, the device body **11** may take on a small form factor. In cases such as these, the components may be packaged and/or in order to provide the most functionality in the smallest space. The components may also be configured to take up a minimal amount of space, which may facilitate the device body **11** having a small form factor. Additionally, the integration and assembly of the various components may be configured to enhance the reliability of the consumer product **10**.

The construction of the housing of the device body **11** may be widely varied. For example, housing may be formed from a variety of materials including plastic, rubber, wood, silicone, glass, ceramics, fiber composites, metal or metal alloys, (e.g., stainless steel, aluminum), precious metals (e.g., gold, silver), or other suitable materials, or a combination of these materials.

Also in the illustrated embodiment, the wearable electronic device includes a band **12** or strap or other means for attaching to a user. The band **12** may, for example, be configured to attach to the body and provide a loop for securing to the wrist of the user. The band **12** may be integral with the housing or it may be a separate part. If integral, the band **12** may be a continuation of the housing. In some cases, the integral band may be formed from the same material as the housing. If the band **12** is separate, the band may be fixed or releasably coupled to the housing. In both cases, the band **12** may be formed from similar or different materials as the housing. In most cases, the band **12** is formed from a flexible material such that it can conform to a user's body. Furthermore, the band **12** itself may be a single integral part or it may include attachment ends that provide an open and closed configuration. The attachment ends may, for example, be manifested as a clasp or other similar attachment mechanism or device. This particular configuration allows a user to open the band **12** for placement on the arm and close the band **12** in order to secure the band and body to the arm. The band **12** may be widely varied. By way of example, they may be formed from rubber, silicone, leather, metal, mesh, links and/or the like.

FIG. **2** depicts an example schematic diagram of a wearable electronic device. By way of example, device **100** of FIG. **2** may correspond to the consumer product **10** shown in FIG. **1**. To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device **100**, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device **100** may have

some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

As shown in FIG. **2**, the device **100** includes one or more processing units **102** that are configured to access a memory **104** having instructions stored thereon. The instructions or computer programs may be configured to perform one or more of the operations or functions described with respect to the device **100**. For example, the instructions may be configured to control or coordinate the operation of a display **120**, one or more input/output components **106**, one or more communication channels **108**, one or more sensors **110**, a speaker **122**, a microphone **124** and/or one or more haptic feedback devices **112**.

The processing units **102** of FIG. **2** may be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processing units **102** may include one or more of: a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

The memory **104** can store electronic data that can be used by the device **100**. For example, a memory can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing and control signals or data for the various modules, data structures or databases, and so on. The memory **104** can be configured as any type of memory. By way of example only, the memory can be implemented as random access memory, read-only memory, Flash memory, removable memory, or other types of storage elements, or combinations of such devices.

In the schematic diagram of FIG. **2**, the one or more input components **106** are represented as a single item within the schematic diagram. However, input components **106** may represent a number of different input components, including buttons, switches, and dials for accepting user input, and so on. More specifically, the input components **106** may correspond to the buttons, dials, crowns or other devices for receiving input. Generally, the input components **106** are configured to translate a user-provided input into a signal or instructions that may be accessed using instructions executed on the processing units **102**. In the present example, the input components **106** may include the hardware configured to receive the user input (e.g., button, switch, crown, and encoder) which is operatively coupled to circuitry and firmware used to generate signals or data that are able to be accessed using processor instructions. Each input component **106** may include specialized circuitry for generating signals or data and, additionally or alternatively, circuitry and firmware for generating signals or data may be shared between multiple input components **106**. In some cases, the input components **106** produce user-provided feedback for application-specific input that corresponds to a prompt or user interface object presented on display **120**. For example, the crown (item **642** of FIG. **6**) may be used to receive rotational input from the user, which may be translated into an instruction to scroll a list or object presented on the display **120**. The input components **106** may also produce user input for system-level operations. For example the input components **106** may be configured to interact directly with hardware or firmware being executed on the device **100** for system-level operations, including, without limitation, power on, power off, sleep, awake, and do-not-disturb operations.

As shown in FIG. **2**, the device **100** may also include one or more acoustic elements, including a speaker **122** and a microphone **124**. The speaker **122** may include drive electronics or circuitry and may be configured to produce an audible sound or acoustic signal in response to a command or input. Similarly, the microphone **124** may also include drive electronics or circuitry and is configured to receive an audible sound or acoustic signal in response to a command or input. The speaker **122** and the microphone **124** may be acoustically coupled to respective ports or openings in the housing that allow acoustic energy to pass, but may prevent the ingress of liquid and other debris. As shown in FIG. **2**, the speaker **122** and microphone **124** are also operatively coupled to the processing units **102**, which may control the operation of the speaker **122** and microphone **124**. In some cases, the processing units **102** are configured to operate the speaker **122** to produce an acoustic output that corresponds to an application or system-level operation being performed on the device **100**. In some cases, the speaker **122** is operatively coupled to other modules, including, for example, input components **106**, such as a crown or button. In some implementations, the device **100** is configured to produce an audible output that corresponds to the operation of the crown or buttons using the speaker **122**. The microphone **124** may be configured to produce an output or signal in response to an acoustic stimulus. For example, the microphone **124** may be operatively coupled to the memory **104** and may be configured to record audio input, including human speech, music, or other sounds. In some cases, the microphone **124** may be configured to receive voice signals, which may be interpreted as voice commands by the processing units **102**.

The one or more communication channels **108** may include one or more wireless interface(s) that are adapted to provide communication between the processing unit(s) **102** and an external device. In general, the one or more communication channels **108** may be configured to transmit and receive data and/or signals that may be interpreted by instructions executed on the processing units **102**. In some cases, the external device is part of an external communication network that is configured to exchange data with wireless devices. Generally, the wireless interface may include, without limitation, radio frequency, optical, acoustic, and/or magnetic signals and may be configured to operate over a wireless interface or protocol. Example wireless interfaces include radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces.

In some implementations, the one or more communications channels **108** may include a dedicated wireless communication channel between the device **100** and another user device, such as a mobile phone, tablet, computer, or the like. In some cases, output, including audio sounds or visual display elements, are transmitted directly to the other user device for output to the user. For example, an audible alert or visual warning may be transmitted to a user's mobile phone for output on that device. Similarly, the one or more communications channels **108** may be configured to receive user input provided on another user device. In one example, the user may control one or more operations on the device **100** using a user interface on an external mobile phone, table, computer, or the like.

Additionally, as described in more detail below with respect to FIG. **17**, the communications channels **108** may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce.

As shown in FIG. **2**, the device **100** also includes one or more sensors **110** represented as a single item within the schematic diagram. However, the sensors **110** may represent a number of different sensors, including devices and components that are configured to detect environmental conditions and/or other aspects of the operating environment. Example sensors **110** include an ambient light sensor (ALS), proximity sensor, temperature sensor, barometric pressure sensor, moisture sensor, and the like. Thus, the sensors **110** may also be used to compute an ambient temperature, air pressure, and/or water ingress into the device. In some embodiments, the sensors **110** may include one or more motion sensors for detecting movement and acceleration of the device **100**. The one or more motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device.

The device **100** also includes one or more biosensors **118** and may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. As described in more detail below with respect to FIG. **16**, one or more of the biosensors **118** may include a light source and a photodetector to form a photoplethysmography (PPG) sensor. The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics including, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. One or more of the biosensors **118** may also be configured to perform an electrical measurement using one or more electrodes. The electrical sensor(s) may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, one or more of the biosensors **118** may be configured to measure body temperature, exposure to UV radiation, and other health-related information.

The device **100** may also include one or more haptic devices **112**. The haptic device **112** may include one or more of a variety of haptic technologies such as, but not necessarily limited to, rotational haptic devices, linear actuators, piezoelectric devices, vibration elements, and so on. In general, the haptic device **112** may be configured to provide punctuated and distinct feedback to a user of the device. More particularly, the haptic device **112** may be adapted to produce a knock or tap sensation and/or a vibration sensation. As shown in FIG. **2**, the haptic device **112** may be operatively coupled to the processing unit **102** and memory **104**. In some embodiments, the haptic device **112** may be directly controlled by the processing unit **102**. In some embodiments, the haptic device **112** may be controlled, at least in part, by the operation of an input component **106**, including, for example, a button, dial, crown, or the like. The operation of the haptic device **112** may also be paired or linked to the operation of one or more other output devices, including, for example, the display **120** or the speaker **122**.

As shown in FIG. **2**, the device **100** may include a battery **114** that is used to store and provide power to the other components of the device **100**. The battery **114** may be a rechargeable power supply that is configured to provide power to the device **100** while it is being worn by the user. The device **100** may also be configured to recharge the battery **114** using a wireless charging system. Accordingly, in some cases, the device may include a wireless power module **116** that may be configured to receive power from an external device or dock. The wireless power module **116** may be configured to deliver power to components of the device, including the battery **114**. The wireless power module **116** and an external charging station or dock may also be configured to transmit data between the device and a base or host device. In some cases, the wireless power module **116** may interface with the wireless charging station or dock to provide an authentication routine that is able to identify specific hardware, firmware, or software on the device in order to facilitate device maintenance or product updates. A more detailed description of an example wireless charging station is provided below with respect to FIGS. **18-19**.

The device **100** may include a variety of other components, including for example, a camera or camera modules. The camera may be configured to capture an image of a scene or subject located within a field of view of the camera. The image may be stored in a digital file in accordance with any one of a number of digital formats. In some embodiments, the device **100** includes a camera, which includes an image sensor formed from a charge-coupled device (CCD) and/or a complementary metal-oxide-semiconductor (CMOS) device. The camera may also include one or more optical components disposed relative to the image sensor, including, for example, a lens, an filter, a shutter, and so on.

FIG. **3** depicts functional elements of the device **100**, in accordance with some embodiments. In particular, FIG. **3** depicts the inputs that may be received and outputs that may be produced on an example device **100**. By way of example, the device **100** may correspond to the devices shown in FIGS. **1** and **2**. As shown in FIG. **3**, the device **100** may include a force input **302** that may be produced using a force sensor that is configured to detect and measure the magnitude of a force of a touch on a surface of the device. The force input **302** may include a non-binary output that is generated in response to a touch. For example, the force input **302** may include a range of values or analog value that corresponds to the amount of force exerted on a surface of the device. Additionally or alternatively, the force input **302** may include binary (e.g., on, off) output in response to the force of a touch. The force input **302** may be used to control various aspects of the device. For example, the force input **302** may be used to control an aspect, such as a cursor or item selection on a user interface presented on the display of the device. The force input **302** may also be used to control the audio output **308**, haptic output **312**, and other functionality of the device. The force input **302** may also be used to distinguish between different types of input from the user. For example, a light touch from the user may be interpreted as a scroll command and used to index or scroll through a list of items on the display. A harder touch from the user may be interpreted as a selection or confirmation of an item on the display. In some embodiments, the force input **302** is used to distinguish an intentional touch from the user from an incidental or accidental touch that may be ignored.

As shown in FIG. **3**, the device **100** may also include a touch input **306** that may be produced using a touch sensor that is configured to detect and measure the location of a touch on a surface of the device. In some implementations, the touch sensor is a capacitive-based touch sensor that is disposed relative to the display or display stack of the device. The touch sensor may be a separate non-integrated sensor relative to the force sensor. In alternative embodiments, the touch sensor may also be physically and/or logically integrated with the force sensor to produce a

combined output. The touch input **306** may be used to control various aspects of the device. For example, the touch input **306** may be used to control an aspect of the user interface presented on the display of the device. The touch input **306** may also be used to control the audio output **308**, haptic output **312**, and other functionality of the device.

In some cases, the logical integration of the force input **302** and the touch input **306** enhances the versatility or adaptability of device **100** by enabling a more sophisticated user interface than is currently available on some traditional wearable devices. In particular, the force input **302** and the touch input **306** may be combined to interpret a wider range of gestures and input commands than may be possible using, for example, only a touch input. For example, the force input **302** may provide a magnitude of a force of a touch, which may be used to distinguish between two touch input commands that have a similar location or gesture path. An improved touch interface using both force input **302** and touch input **306** may be particularly advantageous when interpreting touch commands on a relatively small area surface, such as a display screen or cover glass of a wearable electronic device.

As shown in FIG. **3**, the device **100** may also include a button/dial input **310** that may be produced using an input device that is configured to receive input from the user. As described previously, the device **100** may include one or more buttons disposed on or near an external surface of the housing and are configured to receive input from a user. The device may also include a dial or crown that is configured to accept rotational input from the user. As described in more detail below with respect to FIGS. **24**A-B, the dial or crown may also include a push feature that is adapted to accept input from the user.

The device **100** may also accept audio input **314** using a microphone or other acoustic sensing device. The audio input **314** may be adapted to accept input from the user, including voice commands and other audio signal input. The audio input **314** may also be adapted to detect and measure ambient audio conditions that may be used to adjust the volume of the audio output **308** or operation of the haptic output **312**. The audio input **314** may also be used to record an audio stream or voice message in accordance with an audio recording application or software program.

As shown in FIG. **3**, the device **100** may include a display output **304** in accordance with some embodiments. The display output **304** includes visual or graphical output that may be produced using the display element of the device. In some embodiments, the display output **304** includes a graphical user interface produced using an operating system or software application executed on one or more processing units of the device. In one example, the display output **304** includes a graphical depiction that resembles a watch face or other timekeeping device. In other examples, the display output **304** includes a graphical interface for an e-mail, text messaging, or other communication-oriented program. The display output **304** may also present visual information that corresponds to one of the other functional aspects of the device **100**. For example, the display output **304** may include information that corresponds to the biosensor input **320**, sensor input **318**, force input **302**, touch input **306**, and others.

As shown in FIG. **3** the device **100** may include an audio output **308** that may be produced with a speaker or acoustic module. The audio output **308** may include sounds or audio signals that are associated with the operation of the device. For example, the audio output **308** may correspond to the operation of an input device to provide audio feedback to the user. For example the audio output **308** may correspond to an input received in the form of a force input **302**, touch input **306**, and/or button/dial input **310**. In some cases, the audio output **308** may also include a portion of an auditory alert that may be produced alone or combined with a haptic output **312** and/or display output **304** of the device **100**.

The device **100** may also include a sensor input **318** produced using one or more sensors that may be configured to monitor and detect various environmental conditions. For example, the sensor input **318** may include signals or data produced using an ambient light sensor, proximity sensor, temperature sensor, barometric pressure sensor, or other sensor for monitoring environmental conditions surrounding or near the device. In general, the sensor input **318** may be used to adapt the functionality of the device **100** to conform to the one or more environmental conditions. For example, the brightness of the display output **304**, the volume of the audio output **308**, and/or the operation of the input to the device **100** may be based on the sensor input **318**.

In some embodiments, the sensor input **318** includes input produced by one or more motion sensors. The motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device. A sensor input **318** produced using one or more motion sensors may be used to monitor and detect changes in motion of the device **100**. Changes in linear and angular motion may be used to determine or estimate an orientation of the device relative to a known location or fixed datum. The sensor input **318** produced from the one or more motion sensors may also be used to track the movement of the user. The movement of the user may be used to facilitate navigation or map-guided functionality of the device. Additionally, input related to the gross movement of the user can be used as a pedometer or activity meter, which may be stored and tracked over time to determine health metrics or other health-related information. Additionally, in some embodiments, sensor input **318** from the one or more motion sensors may be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty).

The device **100** may also include a biosensor input **320** produced using one or more biosensors or biosensor modules that are configured to monitor physiological and/or health conditions of a user. As discussed above with respect to FIG. **2**, the device may include one or more optical sensors for measuring heart rate, blood pressure, oxygen saturation, or a combination thereof. The device may also include one or more sensors having electrical contacts that are disposed to contact the user's body. The sensors may be configured to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, sensors may be configured to measure body temperature, exposure to UV radiation, and other health related information. The biosensor input **320** may be combined with other aspects of the device to provide heath-monitoring functionality. For example, the biosensor input **320** may be used to compute data that is presented using the display output **304**. The operation of the biosensor input **320** may also be controlled using the force input **302**, touch input **306**, or other user input **310** to provide an interactive health monitoring function or application.

As shown in FIG. **3**, the device may include a haptic output **312** that may be produced using one or more haptic devices that are configured to provide haptic feedback to the user. In particular, the haptic output **312** may be produced

using one or more electromechanical subassemblies that are configured to induce motion or vibration in the device, which may be perceived or sensed by the user. In some cases, the haptic actuator or device is tuned to operate based on a resonance or near resonance with respect to the device, which may enhance haptic output. In some cases, the haptic actuator or device is configured to operate based on a resonance or near resonance with respect to some components of the device, such as the band or clasp of the device.

In some embodiments, the haptic output **312** may correspond to the operation of one or more other modules or subsystems. For example, the haptic output **312** may include a vibration or haptic feedback that corresponds to an audio alert or visual alert or signal produced by the acoustic module or display, respectively. Additionally or alternatively, the haptic output **312** may be operated in conjunction with an input from the user. The haptic output **312** may include haptic or force feedback that confirms that the user input was or is being received. By way of example, a haptic output **312** may include a click or vibration when the crown of the device is turned or a button is depressed. The haptic output **312** may also be coordinated with other functionality of the device including, for example, message transmission operations, power management operations, force sensor operations, biosensor operations, to provide a notification, to provide an alert, and others.

As shown in FIG. **3**, the device **100** may also include communications input/output (I/O) **316**, which may facilitate communication with an external device or system. The communications I/O **316** may be produced using one or more wireless interfaces, including radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. In some cases, the communications I/O **316** may include signals and data received from an external device that has been paired or is otherwise in electronic communication with the device **100**. The external data included in the communications I/O **316** may include, for example, message data associated with an electronic communication, notification data associated with an event, and/or data related to audio or visual content. The communications I/O **316** may also include an authorization or identification of external devices in communication with the device **100** or users associated with one or more external devices. Similarly, the communications I/O **316** may be used to output various forms of data or signals to one or more devices or systems that are external to the device **100**. For example, the communications I/O **316** may include data or computations that are produced using the biosensor input **320** and/or the sensor input **318**.

FIG. **4** depicts an example wearable electronic device **100** as part of a system of devices. By way of example, the wearable electronic device **100** of FIG. **4** may correspond to the devices shown in any of the previous figures. Generally, the wearable electronic device **100** may communicate wirelessly with any of a number of other devices, such as mobile phone **420**, computer **430**, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Additionally, the wearable electronic device **100** may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. Communication may be through a wired or wireless connection, including any technology mentioned herein.

In some embodiments the wearable electronic device **100** may accept a variety of bands, straps, or other retention mechanisms (collectively, “bands”). These bands may be removably connected to the electronic device by a feature formed into the band or band assembly that is accepted in a recess or other aperture within the device and locks thereto. An example band interface is described in more detail below with respect to FIGS. **25**A-C.

In general, a user may change combinations of bands and electronic devices, thereby permitting mixing and matching of the two categories. It should be appreciated that devices having other forms and/or functions may include similar recesses and may releasably mate with a lug and/or band incorporating a lug. In this fashion, a system of bands and devices may be envisioned, each of which is compatible with another. A single band may be used to connect to devices, as one further example; in such embodiments the band may include electrical interconnections that permit the two devices to transmit signals to one another and thereby interact with one another.

Insofar as the electronic device **100** may connect either physically or through a data communication link with other computing devices, the combination of devices and bands may be thought of as an ecosystem having multiple parts that interact with one another, may intelligently communicate with one another, may share functionality and/or may substitute for one another in terms of operations, output, input and the like. Examples of devices existing in such an ecosystem follow, but are illustrative rather that limiting.

As one example, a number of electronic devices **100**, **420**, **430** may each have identical or similar attachment structures that permit them to share a band or connector. A user may thus change the interconnected band and device(s) with respect to one another, permitting a number of different physical connections between different ecosystem components. In some embodiments, a band that serves to retain an electronic device only may be swapped for bands having additional functionalities, such as transmitting data between devices connected to the band, adding functionality to a connected device that the device lacks, providing additional power to a connected device, and so on. Further, different bands may look different, so that the appearance of the electronic device(s) in combination with a band(s) may change by changing the band(s) and/or device(s) with respect to one another.

As another example, electronic devices **100**, **420**, **430** may communicate with one another as part of the overall ecosystem. Data may be passed from one device **420** to another **100**. This may be useful if the user **410** is wearing one electronic device **100** but is not near another device **430** that wishes to notify the user or interact with the user in some fashion. Continuing the example, the computer **430** may transmit a reminder or message to the wearable device **100** to gain the user’s attention. As another example, the computer **430** (or any other electronic device in the ecosystem) may transmit a state of an application or even the device itself to the wearable device **100**. Thus, for example, if an application operating on the computer needs the user’s attention, it may be gained through an alert issued by the wearable device.

Data communication between devices in an ecosystem may also permit the devices to share functionality. As one non-limiting example, electronic devices may share sensor data with one another to permit one device access to data it

normally would not have, from a sensor it does not physically incorporate. Thus, any given device **100**, **420**, **430** may draw on the abilities of other devices in the ecosystem to provide an enhanced and relatively seamless experience for a user **410**.

FIG. **5** depicts a system **500** of interchangeable components for a wearable device. By way of example, one or more of the devices of FIG. **5** may correspond to the devices shown in any of the previous figures. FIG. **5** depicts a system **500** including a variety of interchangeable components, including multiple device bodies **515**, **525**, **535** that are configured to connect via a standard interface to any one of a number of different bands **551***a-b*, **552***a-b*, **553***a-b*, **554***a-b*, and **555***a-b*. In addition, each of the three devices may be configured to connect via a standard interface to another type of non-band component, such as a lug **556***a-b*, non-band component, or other device.

As shown in FIG. **5**, the system **500** may include a body or device that is adapted to attach to one or more bands, straps, or other similar component that may be used to attach the device to the body of a user. In some embodiments, the device may be interchangeable or interchanged to provide a different set of functions or features. In some embodiments, the bands or attachment components may be interchangeable or interchanged to provide desired functionality or features.

In the example depicted in FIG. **5**, each of the devices includes at least one receiving feature **504** that is configured to interconnect with a corresponding feature **502** that is attached to or integrally formed with the end of each of the bands or other mating parts. In some embodiments, receiving feature **504** includes a channel or groove that is formed in one end of the device body. The mating feature **502** of a respective band or component may be configured to slidably engage with the receiving feature **504** of a respective device body to attach the band or component. An example receiving feature is described in more detail below with respect to FIGS. **25**A-C. In some embodiments, the receiving feature **504** and the mating feature **502** are standardized in the system **500** and, thus, any of the bands (**551***a-b*, **552***a-b*, **553***a-b*, **554***a-b*, and **555***a-b*) can be interchangeably used with any of the device bodies **515**, **525**, **535**.

With respect to FIG. **5**, each of the bands may be formed from a different material or using a different construction. In the present example, bands **551***a-b* may be formed from a textile material that may be constructed from a pattern of thread or fiber material. The textile material may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **552***a-b* may be formed from a woven material and may be constructed from an array of warp fibers or threads interwoven with one or more weft fibers or threads. Similarly, the warp and weft fibers may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **553***a-b* may be formed from leather material **553***a-b*. In one example, the bands **553***a-b* are formed from a sheet or strip of cowhide; however, the bands **553***a-b* may also be formed from one of any number of types of animal hide. The leather material **553***a-b* may also include a synthetic leather material, such as vinyl or plastic. The bands **554***a-b* may be formed from a metallic mesh or link construction. For example the bands **554***a-b* may be formed from a Milanese mesh or other similar type of construction. The bands **555***a-b* may be formed from a silicone or other elastomer material.

In some cases, the band is a composite construction including various materials, which may be selected based on the end use or application. In some embodiments, a first band strap, or a first portion of the first band strap, may be made up of a first material and a second band strap, or a second portion of the second band strap, may be made from a second, different material. The band may also be made up of a plurality of links and, as such, the band may be resizable by, for example, adding or removing links. Example bands and band constructions are provided below in Section 12.

In the system **500**, an interchangeable band may allow for individual customization of the device or to better adapt the device for a range of uses or applications. In some instances, the type of band that is selected and installed can facilitate a particular user activity. For example, band **551***a-b* may be formed from a textile material and include a durable clasp that may be particularly well suited for exercise or outdoor activities. Alternatively, as discussed above the band **554***a-b* may be formed from a metallic material and include a thin or low-profile clasp that may be well suited for more formal or fashion-focused activities.

In some embodiments, the band may be coupled to a separate component having the mating feature **502**. The band may be coupled using pins, holes, adhesives, screws, and so on. In yet other embodiments, the band may be co-molded or overmolded with at least a portion of the component having the mating feature **502**. In some embodiments, the band is coupled to the component via a pin that allows the straps to rotate with respect to the component. The pin may be formed integrally with or disposed in a loop formed in the end of the band.

In the example system **500**, each of the bands is shown as having a generic band clasp. However, the type of band clasp that is used may vary between embodiments. On example band clasp may include a first band strap having a buckle or tang assembly which is configured to interface with a second band strap having a series of apertures or holes formed with the strap. Additionally or alternatively, the bands may include a magnetic clasp having one or more magnetic elements on a first band strap that is configured to mate to one or more magnetic or ferromagnetic elements on a second band strap.

As shown in FIG. **5**, the system may include multiple device bodies **515**, **525**, **535** that may vary in size, shape, and composition. The device body **515**, **525**, **535** may include one or more of the embodiments described herein and may include, but is not limited to a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and/or the like. In particular, the device body may correspond to the device body described with respect to device body **610** of device **100** (shown in FIG. **6**).

1. Example Wearable Electronic Device

FIG. **6** depicts an example wearable electronic device, which may include various aspects of the device(s) described above. In some embodiments, multiple modules or subsystems are physically and operationally integrated together to provide particular functionality or device features. In particular, the interaction between the subsystems, or the subsystems themselves, may be configurable by the user, manufacturer, or vendor to adapt the device to produce certain functionality. Some example combinations and interactions between the various modules and subsystems are expressly provided in the present description. However, the combinations and interactions provided herein are merely illustrative in nature and are not intended to be limiting on the scope of the disclosure.

FIG. **6** depicts an example configuration of a wearable electronic device **100**. In particular, FIG. **6** depicts an electronic wearable device **100** including a device body **610**

that may be configured to be attached to the wrist of a user using a band assembly **620**. This configuration may also be referred to herein as a wearable device, a device, an electronic wristwatch, or an electronic watch. While these terms may be used with respect to certain embodiments, the functionality provided by the example electronic wearable device **100** may be substantially greater than or vary with respect to many traditional electronic watches or timekeeping devices.

In the present example, the exterior surface of the device body **610** is defined, in part, by the exterior surface of the housing **601** and the exterior surface of the cover **609**. In the example depicted in FIG. **6**, the device body **610** is substantially rectangular with round or curved side portions. The outer surfaces of the cover **609** and the housing **601** coincide at a joint interface and cooperate to form a continuous contoured surface. The continuous contoured surface may have a constant radius and may be tangent to a flat middle portion of the cover **609** and/or a flat bottom portion of the housing **601**. In some embodiments, the cover **609** has substantially the same shape as a flat bottom portion and at least a portion of the curved side portions of the housing **601**. A more complete description of the geometry of the cover **609** and the housing **601** is provided below with respect to FIGS. **7** and **8**.

In the example of FIG. **6**, the device **100** includes a display (item **120** of FIG. **2**) that is disposed at least partially within an opening or cavity defined within a top portion of the housing **601** of the device body **610**. The display may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user and may be operated in accordance with one or more display modes or the software applications being executed on the device **100**. By way of example, the display may be configured to present the current time and date similar to a traditional watch or timepiece. The display may also present a variety of other visual information that may correspond to or be produced using one of the other modules in the device **100**. For example, the display may be configured to display one of a variety of notification messages, which may be generated based on data received from the one or more sensors, the wireless communication system, or other subsystem of the device **100**. The display may also be configured to present visual information or data that is based on the output of one or more sensor outputs. The display may also provide status or information related to a wireless charging process or battery power. The display may also present visual output or information related to media being produced using a speaker or acoustic module of the device **100**. Accordingly, a variety of other types of visual output or information may be presented using the display.

In the current example, the display includes or is integrated with a cover **609** that helps to protect the display from physical impact or scratches. In the field of wearable devices, the cover **609** may also be referred to generically as a crystal or cover glass, regardless of the material that is used to form the cover **609**. In some cases, the cover **609** is formed from a sheet or block of sapphire material. Sapphire may provide superior optical and surface hardness properties as compared to other materials. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. In alternative embodiments, the cover **609** is formed from a glass, polycarbonate, or other optically transparent material. The cover **609** may also be coated with one or more optical or mechanical enhancing materials or surface treatments. For example, interior and/or exterior surfaces of the cover **609** may be coated with an anti-reflective (AR), oleophobic or other coating to enhance the visible or functional properties of the display. Additionally, in some cases, the cover **609** may be configured to cooperate with an antenna used to facilitate wireless communication with an external device. FIGS. **21**A-B, described in more detail below, provide one example embodiment of a cover configured to cooperate with an antenna.

In the example depicted in FIG. **6**, the cover **609** is formed from a transparent material and, when assembled has an external surface and an internal surface. The cover **609** is disposed above the display and encloses a cavity or opening formed in the top portion of the housing **601**. In some embodiments, the external surface of the cover **609** cooperates with the external surface of the housing to form a substantially continuous external peripheral surface of the electronic device. As shown in FIG. **6**, the external surface of the cover **609** has a flat middle portion at the center of the cover, which extends outwardly. The cover **609** also includes a curved edge portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge at the side of the cover **609**. In some embodiments, the cover **609** also includes an opaque mask disposed relative to the internal surface of the transparent cover. The opaque mask may correspond to or otherwise define the viewable area of the display **120**. The mask may have an outer boundary that is located proximate the edge of the side of the cover **609** and has an inner boundary located within the curved edge portion of the cover **609**.

As shown in FIG. **6**, the cover **609** is disposed relative to a top portion of the housing **601**. The housing **601** includes a top portion defining an opening, which is surrounded by a curved side portion. In the present example, the curved edge portion of the cover **609** coincides with the curved side portion of the housing **601** to form a continuous external surface of the electronic device **100**. In some instances, the cover **609** may have a contour that follows or otherwise corresponds to a similar contour of the housing **601** to form a substantially continuous surface at the interface between the two components. As shown in FIG. **6**, the cover **609** protrudes above the housing **601**.

In some instances, the cover **609** is disposed relative to a touch sensor (item **702** of FIG. **7**). In some embodiments, the touch sensor may be integrated with the display or other element of the device **100**. The touch sensor may be formed from one or more capacitive sensor electrodes or nodes that are configured to detect the presence and/or location of an object or the user's finger that is touching or nearly touching the surface of the display. In some cases, the touch sensor includes an array of sensing nodes formed in accordance with a mutual capacitance sensing scheme.

In one example, the touch sensor may include an array of mutual capacitance touch nodes that can be formed by a two-layer electrode structure separated by a dielectric material. One layer of electrodes may comprise a plurality of drive lines and another layer of electrodes may comprise a plurality of sense lines, and where the drive lines and the sense lines cross, mutual capacitive sense nodes are formed (also referred to as coupling capacitance). In some implementations, the drive lines and sense lines may cross over each other in different planes separated from one another by a dielectric. Alternatively, in other embodiments the drive lines and sense lines can be formed substantially on a single layer. An example touch sensor and touch-sensing node are described in more detail below with respect to FIGS. **14**A-C and **15**A-B.

Alternatively or additionally, the touch sensor may include one or more self-capacitive nodes or electrodes that are configured to detect a discharge of electrical current or charge when an object, such as a user's finger, contacts or nearly contacts a surface of the housing **601** or other surface of the device **100**. Other types of electronically sensing nodes, including resistive, inductive, or the like, may also be integrated into a surface of the device **100**.

In some embodiments, the device **100** may also include a force sensor (item **705** of FIG. **7**). The force sensor may be disposed relative to the display **120** or integrated with other elements of the device **100**. In some cases, the force sensor includes one or more force sensing structures or force-sensing nodes for detecting and measuring the magnitude of a force or pressure due to a touch on a surface of the device **100**. The force sensor may be formed from or implement one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a force or pressure due to a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on the deflection. Example force sensor and force-sensing modules are described in more detail below with respect to FIGS. **9-12**.

As shown in FIG. **6**, the device **100** also includes device body **610** including a housing **601** that upon which may be mounted or integrated with various components of the device **100**. The housing **601** serves to surround at a peripheral region as well as support the internal components of the product in their assembled position. In some embodiments, the housing **601** may enclose and support internally various components (including for example integrated circuit chips and other circuitry) to provide computing and functional operations for the device **100**. The housing **601** may also help define the shape or form of the device. That is, the contour of the housing **601** may embody the outward physical appearance of the device. As such, it may include various ornamental and mechanical features that improve the aesthetical appearance and tactile feel of the device. For example, the housing **601** may include a contoured surface that includes rectilinear contours, curvilinear contours, or combinations thereof. The housing **601** may also include various surface features, including textures, patterns, decorative elements, and so on.

In the present example, the housing **601** is formed from a single piece, which may also be referred to as single-body, unitary, or uni-body design or construction. By utilizing a single-body construction, the structural integrity of the device may be improved as compared to a multi-piece construction. For example, a single body may be more easily sealed from contaminants as compared to a multi-piece enclosure. Additionally, a single-body enclosure may be more rigid due, in part, to the absence of joints or seams. The rigidity of the housing **601** may be further enhanced by increasing the material thickness in areas where mechanical stress may be greatest, while also maintaining or thinning other areas where mechanical stress may be lower or reduced. Variations in the thickness of the housing **601** may be possible by machining or casting the housing **601** as a single piece. Additionally, a single-body housing **601** may include one or more features for mounting or integrating the internal components of the device **100**, which may facilitate manufacturing and/or assembly of the device **100**.

An example housing **601** is described in more detail below with respect to FIG. **8**. The housing **601** may be formed from a variety of materials, including, without limitation plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, magnesium), other suitable materials, or a combination of these materials. Further, the housing **601** may include a surface treatment or coating, which may be formed from a variety of materials, including, without limitation aluminum, steel, gold, silver and other metals, metal alloys, ceramics, wood, plastics, glasses, and the like.

As discussed above, the display, the touch sensor, and force sensor may be disposed within the housing **601**. In this example, one or more buttons **644** and a crown **642** used to receive user input may also be disposed within or relative to the housing **601**. Other types of user input, including for example, one or more dials, slides, or similar user input devices or mechanisms may also be disposed within or relative to the housing **601**. As described in more detail with respect to FIGS. **7** and **8**, the housing **601** may include various features for attaching and mounting the subassemblies and modules of the device **100**. In particular, the housing **601** may have one or more openings for receiving the cover **609**, the display, the force sensor, or other components. The housing **601** may also include one or more holes or openings for receiving the button **644** and crown **642** that are located around the perimeter of the device **100**. In some embodiments, the housing **601** also includes internal features, such as bosses and threaded portions, that can be used to attach modules or components within the housing **601**.

The device **100** may also include an ambient light sensor (ALS) that is configured to detect and measure changes in ambient lighting conditions. The ALS may include a photodiode and one or more optical elements or lenses for collecting light. An ALS may be located on an external facing surface that is less likely to be blocked when the device is worn or in use. The ALS may be used to adjust settings, including screen brightness and other visual output depending on the overall lighting conditions.

The housing **601** may also include one or more motion-sensing elements or devices for detecting motion of the device **100**. For example, the device **100** may include one or more accelerometers that are configured to sense acceleration or changes in motion. Additionally or alternatively, the device **100** may include one or more gyroscopic sensors that are configured to detect changes in direction. In some cases, the one or more gyroscopic sensors may include a spinning mass that can be used to detect changes in angular velocity. Multiple motion-sensing elements may be used to detect motion along multiple directions or axes. The motion sensors may also be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty). The one or more motion-sensing elements may be used to determine an orientation of the device relative to a known or fixed datum. For example, the device may include a compass and/or global positioning system (GPS) that can be used to identify an absolute position. The one or more motion sensing elements may then measure deviation or movement with respect to the absolute position to track movement of the device or the user wearing the device. In some implementations, the one or more motion-sensing elements are used to detect gross movement of the device or user. The gross movement may be used as

a pedometer or activity meter, which may be tracked over time and used to calculate a health metric or other health-related information.

Described in more detail with respect to FIG. **8**, the housing **601** may also include one or more openings or orifices coupled to an acoustic module or speaker **122**, which may include a speaker and/or a microphone subassembly. Although the housing **601** may include one or more openings or orifices, the housing **601** may still be substantially waterproof/water resistant and may be substantially impermeable to liquids. For example, the opening or orifice in the housing or enclosure may include a membrane or mesh that is substantially impermeable to liquid ingress. Additionally or alternatively, the geometry of the opening or orifice and other internal features of the housing **601** may be configured to reduce or impede the ingress of liquid or moisture into the device **100**. In one example, the opening is formed from one or more orifices that are offset with respect to an internal acoustic chamber or cavity, which may prevent a direct path from the outside of the housing **601** into the acoustic module.

As shown in FIG. **6**, the device **100** includes a device body **610** that may be attached to a user's wrist using a band **620**. In the present example, the band **620** include a first band strap **621** attached to a first receiving feature **623** and a second band strap **622** attached to a second receiving feature **624**. In some embodiments, the first and second band straps **621**, **622** include a lug feature that is configured to attach to the first and second receiving features **623**, **624**, respectively. As shown in FIG. **6**, the free ends of the band straps **621**, **622** are connected with a clasp **625**.

The band straps **621**, **622** are formed from a flexible or compliant material that may be specially configured for a particular application. The band straps **621**, **622** may be formed from a variety of materials, including, for example, leather, woven textiles, or metallic mesh materials. The material and construction of the band straps **621**, **622** may depend on the application. For example, the band straps **621**, **622** may be formed from a woven textile material configured for exposure to impact and moisture typically associated with outdoor activities. In another example, the band straps **621**, **622** may be formed from a metallic mesh material that may be configured to have a fine finish and construction that may be more appropriate for professional or social activities.

Similarly, the clasp **625** of the band **620** may be configured for a particular application or to work with a particular style of band. For example, if the band straps **621**, **622** are formed from a metallic mesh material, the clasp **625** may include a magnetic clasp mechanism. In the present example, the device **100** is configured to be attached to the wrist of a user. However, in alternative embodiments, the device may be configured to be attached to the arm, leg or other body part of the user.

The housing **601** includes one or more features for attaching the band straps **621**, **622**. In the present example, the housing **601** includes a first receiving feature **623** and a second receiving feature **624** for attaching the first band strap **621** and the second band strap **622**, respectively. In this example, the band straps **621**, **622** include a lug portion that is adapted to mechanically engage with the receiving features **623**, **624**. A more detailed description of the receiving features and lugs is provided below with respect to FIGS. **25**A-C. As shown in FIG. **6**, the first **623** and second receiving features **624** may be integrally formed into the housing **601**. In alternative embodiments, the receiving features may be formed from separate parts and may be attached to the housing **601** during manufacturing. In some embodiments, the receiving features **623**, **624** may be configured to release the band straps **621**, **622** from the device body **610** (e.g., the housing **601**). For example, one or both of the receiving features **623**, **624** may include a button or slide, which may be actuated by the user to release a corresponding band strap **621** and **622**. One advantage of a releasable lug is that the user can swap between a variety of bands that may be specially configured for a particular use scenario. For example, some bands may be specially configured for sport or athletic activities and other bands may be configured for more formal or professional activities.

The device **100** may also include a rear cover **608** located on the rear-facing surface of the housing **601** of the device body **610**. The rear cover **608** may improve the strength and/or scratch resistance of the surface of the device **100**. For example, in some embodiments, the rear cover **608** may be formed from a sapphire sheet, zirconia, or alumina material having superior scratch resistance and surface finish qualities. In some cases, the sapphire material has a hardness greater than 6 on the Mohs scale. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. Due to the superior strength of the sapphire material, a cover glass formed from a sapphire sheet may be very thin. For example, the thickness of a sapphire cover sheet may be less 300 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 100 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 50 microns thick. In some embodiments, the rear cover **608** is contoured in shape. For example, the rear cover **608** may have a convex curved surface.

FIG. **7** depicts an example exploded view of various modules and subassemblies of the device **100**. As shown in FIG. **7**, multiple components are configured to be disposed within and/or attached to the housing **601**. The exploded view provided in FIG. **7** depicts one example arrangement of the components of the device **100**. However, in other embodiments, arrangement, placement, and/or grouping of the subassemblies and the components of the subassemblies may vary.

In the present example, a main cavity of the housing **601** houses an electronics subassembly **720** and the battery **114** of the device. The electronics subassembly **720** includes one or more electrical circuit assemblies for coupling the various electrical components of the device **100** to each other and to power supplied by the battery **114**. The electronics subassembly **720** may also include structural elements or components that provide structural rigidity for the electronics subassembly **720** and/or structural mounting or support for other components disposed within the housing **601**. As shown in FIG. **7**, within the cavity of the housing **601**, the speaker **122**, the crown module **642**, and the battery **114** are all disposed above the electronics subassembly **720**. In the present embodiment the top surface of the speaker **122**, the crown module **642**, and the battery **114** have a substantially similar height. In some embodiments, the speaker **122**, the crown module **642**, and the battery **114**, when assembled in the housing **601**, define an area for the display **120** within the cavity. Thus, as shown in FIG. **7**, the display **120** may overlay the speaker **122**, the crown module **642**, and the battery **114**, which overlay the electronics subassembly **720**.

As shown in FIG. **7**, the cover **609** is configured to fit within a corresponding recess formed within the housing **601**. In particular, the cover **609** includes a vertical portion having a height that corresponds to the depth of the recess formed within the housing **601**. In this example, the device **100** includes a force sensor **705** disposed between the housing **601** and a cover subassembly **704**. As described in

more detail below with respect to FIGS. **9** and **10**A-B, the force sensor **705** may be configured to detect a force placed on a surface of the cover **609** by detecting a relative deflection between the cover **609** (or cover subassembly **704**) and the housing **601**. In the present example, the force sensor **705** also forms a gasket or seal between the cover subassembly **704** and the housing **601**. In some implementations, the seal is a water-proof or water-resistant seal that helps to prevent water or liquid ingress into the internal cavity of the housing **601**. The force sensor **705** may also be used to join the cover subassembly **704** to the housing **601** using an adhesive or film.

In some embodiments, the cover subassembly **704** includes the cover **609** which is disposed above the touch sensor **702** and display **120**. In the present example, the touch sensor **702** and the display **120** are attached to each other by an optically clear adhesive layer (OCA). Similarly, an OCA layer is used to attach the touch sensor **702** to the cover **609**. Other adhesives or bonding techniques may be used to attach the display **120** and the touch sensor **702** to the cover **609**. In some embodiments, the touch sensor **702** is integrated into the display **120** and the display **120** (and integrated touch sensor **702**) are attached to the cover **609**.

As shown in FIG. **7**, the speaker **122** is also disposed within the cavity of the housing **601**. The speaker **122** is adapted to mechanically and acoustically interface with a port formed in the side of the housing **601**. In some embodiments, the port is configured to prevent a direct path for water or liquid into an acoustic chamber or cavity of the speaker **122**. In some embodiments, the device **100** also includes a microphone that is similarly coupled to another port formed in the side of the housing **601**. A more detailed description of the speaker **122** and microphone is provided below with respect to the acoustic module of FIG. **20**.

In the present example, the haptic device **112** is also disposed within the cavity of the housing **601** proximate to the speaker **122**. In some embodiments, the haptic device **112** is rigidly mounted to a portion of the housing **601**. A rigid mounting between the housing **601** and the haptic device **112** may facilitate the transmission of vibrations or other energy produced by the haptic device **112** to the user. In the present example, the haptic device **112** includes a moving mass that is configured to oscillate or translate in a direction that is substantially parallel with a rear face of the housing **601**. In some implementations, this orientation facilitates the perception of a haptic output produced by the haptic device **112** by a user wearing the device **100**. While this configuration is provided as one example, in other implementations, the haptic device **112** may be placed in a different orientation or may be configured to produce a haptic response using a rotating mass or other type of moving mass.

As shown in FIG. **7**, the device also includes an antenna subassembly **722**. In this example, a portion of the antenna subassembly **722** is disposed within the housing **601** and a portion of the antenna subassembly **722** is disposed within the cover assembly. In some implementations, a portion of the antenna subassembly **722** is disposed relative to a feature formed within the cover **609**. An example embodiment is described in more detail below with respect to FIGS. **21**A-B.

In the example depicted in FIG. **7**, the device **100** also includes a crown module **642** which is disposed in an aperture or hole in the housing **601**. When installed, a portion of the crown module **642** is located outside of the housing **601** and a portion of the crown module **642** is disposed within the housing **601**. The crown module **642** may be configured to mechanically and/or electrically cooperate with the electronics subassembly **720**. A more detailed description of an example crown module is provided below with respect to FIGS. **23** and **24**A-B. The housing **601** also includes a button **644**, which is disposed in an opening of the housing **601** and may be configured to mechanically and/or electrically cooperate with the electronics subassembly **720**.

In the example depicted in FIG. **7**, a biosensor module **710** is disposed in an opening formed in the rear surface of the housing **601**. In some embodiments, the biosensor module **710** includes the rear cover **608** and may also include a chassis or plate that facilitates attachment of the biosensor module **710** to the housing **601**. The chassis or plate or the cover sheet **608** may also include features or elements that facilitate a watertight seal between the biosensor module **710** and the housing **601**. For example, the rear cover **608** may include a shelf or flange that may be used to form a seal between the biosensor module **710** and the housing **601**. As described in more detail below with respect to FIG. **16**, the biosensor module **710** may include one or more light sources, one or more photodetectors, and one or more electrodes or conductive elements that are configured to detect and measure a physiological condition or property of the user.

In some embodiments, the rear cover **608** has an edge that protrudes outwardly from the back surface of the housing **601**. The rear cover **608** may also have a convex curved area located between the edges of the rear cover **608**. The convex curved area of the rear cover **608** may include one or more windows or apertures that provide operational access to one or more internal components located within the housing **601**. In some embodiments, the windows have a curvature that matches the curvature of the convex curved area of the rear cover.

2. Example Housing

As described above, a wearable electronic device may include a device body that includes a housing or enclosure shell. As previously described, the housing may function as a chassis that physically integrates the various components of the device. The housing may also form a protective shell or housing for the components and function as a barrier against moisture or debris. In the present examples, the housing is formed as a uni-body, unitary, or single body or component. A single-body construction may be advantageous by providing mounting features directly into the housing, which may reduce space, reduce part count, and increase structural rigidity as compared to some alternative configurations. Additionally, a single-body construction may improve the housing's ability to prevent the ingress of moisture or debris by reducing or eliminating seams or joints between external components.

FIG. **8** depicts an example housing **601** in accordance with some embodiments. In the present example, the housing **601** is formed as a single body or component. As shown in FIG. **8**, the housing **601** is formed as a single part or body. The housing **601** may be formed, for example, by machining or shaping a solid or cast blank having the approximate shape of the housing **601**. In some implementations, the housing **601** may be configured to provide structural integrity for potentially delicate internal components and also withstand a reasonable impact.

In the present embodiment, the housing **601** is formed as a uni-body, unitary, or single-body construction having a flat bottom portion **801** and a top portion including flange **812**. The top portion defines an internal cavity **805**, which is surrounded by four sides **802***a-d* that are integrally formed with the bottom portion **801**. The internal cavity **805** can also be described as being defined by the top portion, the four

sides **802***a-d* and the bottom portion **801**. In this example, the internal cavity **805** has a rectangular (square) shape, although the specific shape may vary with different implementations. In the present example, the four sides **802***a-d* define a curved side portion of the housing **601** that extends from the bottom portion **801** to the top portion of the housing **601**. Each side **802***a-d* is orthogonal to an adjacent side and each side **802***a-d* is connected to an adjacent side by a rounded corner. For example, side **802***a* is orthogonal to two adjacent sides **802***b* and **802***d* and is connected to those sides by respective rounded corners. The shape or contour of the rounded corners may correspond to the curvature of the curved portion of the housing **601**. Specifically, the curvature of the rounded corners may match or correspond to the curvature of the continuous external surface formed by the housing **601** and the cover **609**, as described above with respect to FIG. **6**.

The sides **802***a-d* may vary in thickness in order to provide the structural rigidity for the device. In general, areas of high stress may have an increased material thickness as compared to areas of low stress, which may have a reduced material thickness. In particular, portions of the sides **802***a-d* near the bottom portion **801** may have an increased thickness as compared to portions of the sides **802***a-d* located further away from the bottom portion **801**. This configuration may improve the structural rigidity and overall stiffness of the housing **601**.

As shown in FIG. **8**, one or more mounting features may be formed directly into the housing **601**, which may reduce the number of parts and also enhance the structural integrity of the device. As shown in FIG. **8**, receiving features **623**, **624** may be formed as channels or openings that are configured to receive an end of a band (e.g., a lug) having a mating feature. As described above with respect to FIG. **5**, the receiving features **623**, **624** may be standardized and configured to work with a system of interchangeable components. Forming the receiving features **623**, **624** directly into the housing **601** may reduce parts and also facilitate structural rigidity of the device.

In the example depicted in FIG. **8**, the housing **601** can be described as having two ends (a first end and a second end opposite the first end), and a first side and a second side opposite the first side, the sides being continuous with the ends. In this example, the first and second ends and the first and second sides having an outwardly curved three-dimensional shape. In this example, the receiving feature **623** is formed from a first groove situated in the first end. Similarly, the receiving feature **624** is formed from a second groove situated in the second end. In the present example the grooves have openings at the interface of the first and second sides and first and second ends. As shown in FIG. **8** the groove also has an inwardly curved concave three-dimensional shape with an undercut feature. For example, the middle portion of the groove of receiving features **623**, **624** may have a width that is greater than the opening of the receiving features **623**, **624**. In some embodiments, the upper portion of the housing overhangs the lower portion of the housing at the groove opening. In the example depicted in FIG. **8**, the groove is cut into a solid portion of the housing such that the groove forms a continuous interior shape.

The geometry of the receiving features may be located with respect to other features or components of the device. In the example depicted in FIG. **8**, at least a portion of the groove of the receiving features **623**, **624** may be disposed underneath the cover (item **609** of FIGS. **6-7**). With respect to FIG. **6**, the groove of the receiving features **623**, **624** is located underneath the opening for the cover, which is defined by the sealing ledge **810** and flange **812** formed in the upper portion of the housing **601**. In some embodiments, the length of the groove extends further than the width of the opening configured to receive the cover (and thus the cover, when assembled). In some embodiments, the grooves are formed at an angle relative to the centerline of the housing. In some cases, the angle is approximately 5 degrees. In some embodiments, the groove is located underneath the centerline of the housing **601**. In some embodiments, the groove is angled upward toward the top of the housing **601** and inward toward the center of the housing **601**. The groove may angle upward and cross the centerline of the housing. In some cases, the groove crosses the vertical centerline of the housing **601**.

In the present embodiment, the housing **601** also includes an aperture **821** formed into the side **802***c* of the housing **601** for attaching a crown or crown module (item **642** of FIGS. **6-7**). In some embodiments, the aperture **821** for the crown is offset upwardly from the centerline of the housing **601**. In some embodiments, the aperture **821** for the crown is positioned such that an upper portion of a crown (when installed) is higher than the interface of cover **609** and housing **601**. With respect to FIG. **6**, the interface may correspond to the upper edge of the flange **812**.

The housing **601** also includes an opening **822** formed into the side **802***c* of the housing **601** for attaching the button (item **644** of FIGS. **6-7**). In some embodiments, the aperture **821** for the crown and the opening **822** for the button are disposed with the length defined by a flat part of the cover. In some embodiments, the aperture **821** for the crown is disposed above the centerline of the housing **601** and the opening **822** for the button is disposed below the centerline of the housing **601**. In some embodiments, the aperture **821** for the crown and the opening **822** for the button are disposed on a curved surface of the housing **601**. The housing **601** may also include various other internal features, including threaded features and bosses, for attaching other internal components of the device.

In some cases, the housing **601** may be formed as a single-piece or integral enclosure shell to enhance the structural rigidity and/or liquid-sealing properties of the device. As described above with respect to FIGS. **6** and **7**, the housing **601** may be integrated with a cover (e.g., crystal) and other external components to provide a substantially sealed housing. In the present embodiment, the housing **601**, includes a sealing ledge **810** formed around the perimeter of the main cavity **805** formed within the housing **601**. In some embodiments, the sealing ledge **810** (and thus the cover when installed) is located in the center of the housing **601**. The sealing ledge **810** may be defined by a substantially flat portion **811** that is adapted to form a seal between the housing **601** and another component (e.g., the force sensor **705** or cover **609** of FIGS. **6-7**). The sealing ledge **810** may be formed at a depth that is substantially similar or corresponds to the thickness of the mating cover.

As shown in FIG. **8**, the sealing ledge **810** may also include flange **812** that protrudes from the flat portion and forms a continuous surface with the side walls **802***a-d*. In some cases, the flange **812** is configured to cooperate with the cover (item **609** of FIGS. **6-7**) to form a substantially continuous surface. In some implementations, the sides **802***a-d* and the cover or crystal are configured to cooperate or mechanically interface to improve the strength and the water sealing properties of the device.

As also shown in FIG. **8**, an opening or aperture **815** may be formed in the bottom portion **801** of the housing **601**. In some embodiments, the opening or aperture **815** is located

at the center of the housing **601**. As described above with respect to FIG. **7**, the aperture **815** may be used to integrate a sensor array or other module used to collect measurements that may be used to compute a health metric or other health-related information. The present embodiment may be advantageous by integrating multiple components in a single opening **815**, which may facilitate a water-proof or water-resistant property of the device. Additionally, by integrating a sensor array into a module that attaches via the opening **815**, same housing **601** may be used with a variety of sensing configurations or arrays. For example, the number or sensors or components may be increased or decreased without modifying the housing **601**. This may allow for flexibility in the product development and may facilitate upgrades as new sensing configurations are available.

As previously discussed above with respect to FIGS. **6-7**, the housing **601** may also be configured to serve as a protective housing for one or more acoustic elements, such as a microphone or speaker. Additionally, in some embodiments, the housing **601** may also be configured to inhibit the ingress of foreign particulate or moisture. In particular, the housing **601** may include a speaker port having orifices **831**, **832** that are configured to transmit acoustic signals but also prevent the ingress of liquid or other foreign particulate. In the present example, the speaker port includes orifices **831**, **832** that are offset with respect to an acoustic chamber or cavity to prevent the direct ingress of liquid into the speaker subassembly or acoustic module. In the present example, a shielding or umbrella portion of the housing, which is substantially free of openings, is formed between the orifices **831**, **832**, which helps to prevent the direct ingress of liquid. Similarly, the housing **601** includes a microphone port having orifices **833**, **834** that are offset from a corresponding acoustic chamber or cavity to prevent the direct ingress of liquid into the microphone subassembly or acoustic module.

In the example depicted in FIG. **8**, the orifices **831**, **832** of the speaker port are located on one side of the aperture **821** for the crown and the orifices **833**, **834** for the microphone are located on the other side of the aperture **821**. Both the orifices **831**, **832** of the speaker port and the orifices **833**, **834** for the microphone are located on a curved portion of the housing **601**.

3. Example Force Sensor and Touch Sensor

As discussed previously, a wearable electronic device may include one or more sensors for detecting the location and force of a touch. For the purposes of the following description of the force sensor and touch sensor, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100** including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a force sensor and a touch sensor may be disposed relative to the display of a wearable electronic device for to form a touch-sensitive surface. The following description is provided with respect to individual force and touch sensors that may be used to determine the force and location of a touch, respectively. However, in some embodiments, a single integrated sensor may be used to detect both the force and location of a touch on the device.

In one embodiment, an output from a force sensor may be combined with a touch sensor to provide both location and force of a single touch or of multiple touches on the surface of a device. In an alternative embodiment, a hybrid or integrated force and touch sensor may be used to sense both touch force and location of a single touch or of multiple touches. In either embodiment, by sensing both the force and location of a touch, multiple types of user input may be generated and interpreted. In one example, a first touch may be correlated with a first force and a first touch location or gesture. Based on the magnitude of the force, the first touch may be interpreted as a first type of input or command. A second touch may be sensed as having a second, different force and a similar location or gesture as the first touch. Based in part on the magnitude of the second force, the second touch may be interpreted as a second type of input or command. Thus, a force sensor (alone or in combination with another touch sensor) may be used to produce different responses or outputs depending on the force of the touch.

The one or more force sensors may be formed from or may be implemented as one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on a deflection of the surface, such as the cover glass.

By way of example, the force sensor may include a capacitive force sensor, which may be formed from one or more capacitive plates or conductive electrodes that are separated by a compressible element or other compliant member. As a force is applied to a surface of the device, the compressible element may deflect resulting in a predictable change in the capacitance between the plates or electrodes. In some implementations, a capacitive force sensor may be formed from transparent materials and disposed over the display. In other implementations, a capacitive force sensor may be formed from non-transparent materials and disposed beneath or around the perimeter of a display.

FIG. **9** depicts a detail cross-sectional view of a portion of a force sensor **900** that may be arranged around the perimeter of a display **120**. As shown in FIG. **9**, a force-sensing structure **901** of the force sensor **900** may be disposed beneath the cover **609** and along the side of an edge or the perimeter of the display **120**. In this example, the force sensor **900** is configured to detect and measure the force of a touch on the surface **911** of the cover **609**. In the present embodiment, a first capacitive plate **902** is fixed with respect to the cover **609**. A second, lower capacitive plate **904** is fixed with respect to the housing **601** and may be disposed on a shelf or mounting surface located along the perimeter of the device. The first capacitive plate **902** and the second capacitive plate **904** are separated by a compressible element **906**.

In the configuration depicted in FIG. **9**, a touch on the surface **911** of the device may cause a force to be transmitted through the cover **609** of the device and to the force sensor **900**. In some cases, the force causes the compressible element **906** to compress, thereby bringing the first capacitive plate **902** and the second capacitive plate **904** closer together. The change in distance between the first and second capacitive plates **902**, **904** may result in a change of capacitance, which may be detected and measured. For example, in some cases, a force-sensing circuit may measure this change in capacitance and output a signal that corresponds to the measurement. A processor, integrated circuit or other electronic element may correlate the circuit output to an estimate of the force of the touch. Although the term "plate" may be used to describe certain elements, such as the capacitive plates or conductive electrodes, it should be

appreciated that the elements need not be rigid but may instead be flexible (as in the case of a trace or flex).

FIG. **10**A depicts an example configuration of the force sensor **1000** having four individual force-sensing structures **1001***a-d* arranged around the perimeter of a display in a device. For the sake of clarity, the crystal, display, and other elements of the device are omitted from the depiction of FIG. **10**A. Each of the force-sensing structures **1001***a-d* may be formed from a pair of capacitive plates separated by a compressible element. Additionally, each force-sensing structure **1001***a-d* may be separated by a small gap at or near the corners of the opening in the housing **601**. In the example depicted in FIG. **10**A, the four individual force-sensing structures **1001***a-d* may each be operatively coupled to force-sensing circuitry that is configured to detect a change in the capacitance of each force-sensing structure **1001***a-d*. Using the example arrangement depicted in FIG. **10**A, the approximate location of the touch may be determined by comparing the relative change in capacitance of each force-sensing structure **1001***a-d*. For example, a change in capacitance of structure **1001***b* that is larger as compared to a change in capacitance of structure **1001***d* may indicate that the touch is closer to structure **1001***b*. In some embodiments, the degree of the difference in the change in capacitance may be used to provide a more accurate location estimate.

While the configuration shown in FIG. **10**A depicts the force-sensing structures as individual elements separated by a small gap, in some embodiments, the force-sensing structure may be formed as a single continuous piece. FIG. **10**B depicts a force sensor **1050** formed as a single force-sensing structure **1051** formed as a continuous part along the perimeter of the display. Similar to the example described above, the force-sensing structure **1051** may be operatively coupled to force sensing circuitry that is configured to detect a change in the capacitance of one or more capacitive elements of the force-sensing structure **1051**. While the force-sensing structure **1051** is formed as a continuous structure, there may be multiple sensing elements (e.g., capacitive plates) that are disposed within the structure at different locations, and which may be configured to detect deflection or compression of the structure over a portion of entire area of the force-sensing structure **1051**. In some embodiments, the force-sensing structure **1051** may also function as a seal or gasket to prevent ingress of moisture or other foreign contaminants into the main cavity of the housing. Additionally, the force-sensing structure **1051** may be integrated with one or more sealing or adhesive layers that also function as a barrier for foreign contaminants.

As mentioned previously, the force sensor may additionally or alternatively include a strain-based sensing configuration. The strain-based sensing configuration may include, for example, a charge-based or resistive sensor configuration. FIG. **11** depicts a cross-sectional view of a device having an example force sensor **1100** that uses one or more force-sensitive films to detect and measure the force of a touch on a surface **1111** of the cover **609**. In this example, the force sensitive film **1102** and **1104** are formed from a transparent material and are disposed relative to a viewable portion of the display **120**. As shown in FIG. **11**, the force sensor **1100** includes a first force-sensitive film **1102** and a second force-sensitive film **1104** that are separated by one or more intermediate layers **1106**. The force-sensitive films **1102**, **1104** may be configured to produce different electrical outputs in response to a strain or deflection of the cover **609**. In some cases, the intermediate layer **1106** is compressible to allow the first force-sensitive film **1102** to deflect with respect to the second force-sensitive film **1104**. In other

cases, the intermediate layer **1106** may not be compressible and the first force-sensitive film **1102** deflects in a predictable manner with respect to the second force-sensitive film **1104**. While FIG. **11** depicts an example force sensor **1100** having two force-sensitive films, alternative embodiments may include only a single force-sensitive film or, alternatively, include more than two force-sensitive films.

In general, a transparent force-sensitive film may include a compliant material that exhibits an electrical property that is variable in response to deformation or deflection of the film. The transparent force-sensitive film may be formed from a piezoelectric, piezo-resistive, resistive, or other strain-sensitive materials. Transparent resistive films can be formed by coating a substrate with a transparent conductive material. Potential transparent conductive materials include, for example, polyethyleneioxythiophene (PEDOT), indium tin oxide (ITO), carbon nanotubes, graphene, silver nanowire, other metallic nanowires, and the like. Potential substrate materials include, for example, glass or transparent polymers like polyethylene terephthalate (PET) or cyclo-olefin polymer (COP). Typically, when a piezo-resistive or resistive film is strained, the resistance of the film changes as a function of the strain. The resistance can be measured with an electrical circuit. In this way, a transparent piezo-resistive or resistive film can be used in a similar fashion as a strain gauge.

If transparency is not required, then other film materials may be used, including, for example, Constantan and Karma alloys for the conductive film and a polyimide may be used as a substrate. Nontransparent applications include force sensing on track pads or the back of display elements. In general, transparent and non-transparent force-sensitive films may be referred to herein as "force-sensitive films" or simply "films."

In some embodiments, the force-sensitive film is patterned into an array of lines, pixels, or other geometric elements herein referred to as film elements. The regions of the force-sensitive film or the film elements may also be connected to sense circuitry using electrically conductive traces or electrodes. FIG. **12** depicts a cross-sectional view a device having a strain-based force sensor **1200** formed from one or more strain pixel elements **1202** and **1204** separated by intermediate layer **1206**. Each of the pixel elements **1202**, **1204** may be separated by a gap **1210**. In the present example, each pixel element **1202**, **1204** may exhibit a measurable change in an electrical property in response to a force being applied to the device. By way of example, as a force is applied to a surface **1211** on the cover **609**, one or more of the pixel elements **1202**, **1204** is deflected or deformed. Sense circuitry, which is in electrical communication with the one or more pixel elements **1202**, **1204**, may be configured to detect and measure the change in the electrical property of the film due to the deflection. Based on the measured electrical property of the pixel elements **1202**, **1204**, an estimated amount of force can be computed. In some cases, the estimated force may represent the magnitude of a touch on the surface **1211** of the device, and be used as an input to a graphical user interface or other element of the device. Additionally, in some embodiments, the relative strain of the individual pixel elements may be compared to estimate a location of the touch. While FIG. **12** depicts an example force sensor **1200** having two layers of pixel elements, alternative embodiments may include only a single layer of pixel elements or, alternatively, include more than two layers of pixel elements.

The pixel elements **1202**, **1204** may be specifically configured to detect strain along one or more directions. In some

cases, each pixel element **1202**, **1204** includes an array of traces generally oriented along one direction. This configuration may be referred to as a piezo-resistive or resistive strain gauge configuration. In general, in this configuration the force-sensitive-film is a material whose resistance changes in response to strain. The change in resistance may be due to a change in the geometry resulting from the applied strain. For example, an increase in length combined with decrease in cross-sectional area may occur in accordance with Poisson's effect. The change in resistance may also be due to a change in the inherent resistivity of the material due to the applied strain. For example, the applied strain may make it easier or harder for electrons to transition through the material. The overall effect is for the total resistance to change with strain due to the applied force.

Further, in a piezo-resistive or resistive strain gauge configuration, each pixel may be formed from a pattern of the force-sensitive-film, aligned to respond to strain along a particular axis. For example, if strain along an x-axis is to be measured, the pixel should have a majority of its trace length aligned with the x-axis. By way of example, FIG. **13**A depicts a pixel element **1302** having traces that are generally oriented along the x-axis and may be configured to produce a strain response that is substantially isolated to strain in the x-direction. Similarly, FIG. **13**B depicts a pixel element **1304** having traces that are generally oriented along the y-axis and may be configured to produce a strain response that is substantially isolated to strain in the y-direction.

In some embodiments, the force-sensitive film may be formed from a solid sheet of material and is in electrical communication with a pattern of electrodes disposed on one or more surfaces of the force-sensitive film. The electrodes may be used, for example, to electrically connect a region of the solid sheet of material to sense circuitry. This configuration may be referred to as a piezo-strain configuration. In this configuration, the force-sensitive film may generate a charge when strained. The force-sensitive film may also generate different amounts of charge depending on the degree of the strain. In some cases, the overall total charge is a superposition of the charge generated due to strain along various axes.

As mentioned previously, a force sensor may be combined with a touch sensor that is configured to detect and measure the location of a touch on the surface of the device. FIG. **14**A depicts a simplified schematic representation of an example mutual capacitance touch sensor. As shown in FIG. **14**A, a touch sensor **1430** may be formed by an array of nodes **1402** formed at the intersection of an array of drive lines **1404** and sense lines **1406**. In this example, stray capacitance C_{stray} may be present at each node **1402** (although FIG. **14**A depicts only one C_{stray} for one column for purposes of simplifying the figure). In the example of FIG. **14**A, AC stimuli V_{stim} **1414**, V_{stim} **1415** and V_{stim} **1417** can be at different frequencies and phases. Each stimulation signal on a row can cause a charge $Q_{sig}=C_{sig}\times V_{stim}$ to be injected into the columns through the mutual capacitance present at the affected nodes **1402**. A change in the injected charge (Q_{sig_sense}) can be detected when a finger, palm or other object is present at one or more of the affected nodes **1402**. V_{stim} signals **1414**, **1415** and **1417** can include one or more bursts of sine waves. Note that although FIG. **14**A illustrates rows **1404** and columns **1406** as being substantially perpendicular, they need not be aligned, as described above. Each column **1406** may be operatively coupled to a receive channel of a charge-monitoring circuit.

FIG. **14**B depicts a side view of an exemplary node in a steady-state (no touch) condition according to examples of the disclosure. In FIG. **14**B, electric field lines **1408** between a column **1406** and a row **1404** separated by dielectric **1410** is shown at node **1402**.

FIG. **14**C depicts a side view of an exemplary pixel in a dynamic (touch) condition. An object such as finger **1412** can be placed near node **1402**. Finger **1412** can be a low-impedance object at signal frequencies, and can have an AC capacitance C_{finger} from the column trace **1406** to the body. The body can have a self-capacitance to ground C_{body} of about 200 pF, where C_{body} can be much larger than C_{finger}. If finger **1412** blocks some electric field lines **1408** between row and column electrodes (those fringing fields that exit the dielectric **1410** and pass through the air above the row electrode), those electric field lines can be shunted to ground through the capacitance path inherent in the finger and the body, and as a result, the steady state signal capacitance C_{sig} can be reduced by DC_{sig}. In other words, the combined body and finger capacitance can act to reduce C_{sig} by an amount DC_{sig} (which can also be referred to herein as C_{sig_sense}), and can act as a shunt or dynamic return path to ground, blocking some of the electric field lines as resulting in a reduced net signal capacitance. The signal capacitance at the pixel becomes $C_{sig}-DC_{sig}$, where DC_{sig} represents the dynamic (touch) component. Note that $C_{sig}-DC_{sig}$ may always be nonzero due to the inability of a finger, palm or other object to block all electric fields, especially those electric fields that remain entirely within the dielectric material. In addition, it should be understood that as finger **1412** is pushed harder or more completely onto the touch sensor, finger **1412** can tend to flatten, blocking more and more of the electric fields lines **1408**, and thus DC_{sig} may be variable and representative of how completely finger **1412** is pushing down on the panel (i.e., a range from "no-touch" to "full-touch").

Additionally or alternatively, the touch sensor may be formed from an array of self-capacitive pixels or electrodes. FIG. **15**A depicts an example touch sensor circuit corresponding to a self-capacitance touch pixel electrode and sensing circuit. Touch sensor circuit **1509** can have a touch pixel electrode **1502** with an inherent self-capacitance to ground associated with it, and also an additional self-capacitance to ground that can be formed when an object, such as finger **1512**, is in proximity to or touching the touch pixel electrode **1502**. The total self-capacitance to ground of touch pixel electrode **1502** can be illustrated as capacitance **1504**. Touch pixel electrode **1502** can be coupled to sensing circuit **1514**. Sensing circuit **1514** can include an operational amplifier **1508**, feedback resistor **1516**, feedback capacitor **1510** and an input voltage source **1506**, although other configurations can be employed. For example, feedback resistor **1516** can be replaced by a switch capacitor resistor. Touch pixel electrode **1502** can be coupled to the inverting input of operational amplifier **1508**. An AC input voltage source **1506** can be coupled to the non-inverting input of operational amplifier **1508**. Touch sensor circuit **1509** can be configured to sense changes in the total self-capacitance **1504** of touch pixel electrode **1502** induced by finger **1512** either touching or in proximity to the touch sensor panel. Output **1520** can be used by a processor to determine a presence of a proximity or touch event, or the output can be inputted into a discreet logic network to determine the presence of a touch or proximity event.

FIG. **15**B depicts an example self-capacitance touch sensor **1530**. Touch sensor **1530** can include a plurality of touch pixel electrodes **1502** disposed on a surface and coupled to sense channels in a touch controller, can be driven by stimulation signals from the sense channels through drive/sense interface **1525**, and can be sensed by the sense

channels through the drive/sense interface **1525** as well. After touch controller has determined an amount of touch detected at each touch pixel electrode **1502**, the pattern of touch pixels in the touch screen panel at which touch occurred can be thought of as an "image" of touch (e.g., a pattern of fingers touching the touch screen). The arrangement of the touch pixel electrodes **1502** in FIG. **15**B is provided as one example; however, the arrangement and/or the geometry of the touch pixel electrodes may vary depending on the embodiment.

As previously mentioned, a force sensor may be implemented alone or in combination with another type of touch sensor to sense both touch force and touch location, which may enable more sophisticated user touch input than using touch location alone. For example, a user may manipulate a computer-generated object on a display using a first type of interaction using a relatively light touch force at a given touch location. The user may also interact with the object using a second type of interaction by using a relatively heavy or sharper touch force at the given location. As one specific example, a user may manipulate or move a computer-generated object, such as a window, using a relatively light touch force. Additionally or alternatively, the user may also select or invoke a command associated with the window using a relatively heavy or sharper touch force. In some cases, multiple types of interactions may be associated with multiple amounts of touch force.

Additionally, it may be advantageous for the user to be able to provide an analog input using a varying amount of force. A variable, non-binary input may be useful for selecting within a range of input values. The amount of force may, in some cases, be used to accelerate a scrolling operation, a zooming operation, or other graphical user interface operation. It may also be advantageous to use the touch force in a multi-touch sensing environment. In one example, the force of a touch may be used to interpret a complex user input performed using multiple touches, each touch having a different magnitude or degree of force. As a specific but non-limiting example, touch and force may be used in a multi-touch application that allows the user to play a varying tone or simple musical instrument using the surface of the device. In such a housing, the force of each touch may be used to interpret a user's interaction with the buttons or keys of a virtual instrument. Similarly, the force of multiple touches can be used to interpret a user's multiple touches in a game application that may accept multiple non-binary inputs at different locations.

4. Sensor or Biosensor Module

As described above with respect to FIG. **2**, a wearable electronic device may include one or more sensors that can be used to calculate a health metric or other health-related information. For the purposes of the following description of the biosensor module, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100** including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a wearable electronic device may function as a wearable health assistant that provides health-related information (whether real-time or not) to the user, authorized third parties, and/or an associated monitoring device. The wearable health assistant may be configured to provide health-related information or data such as, but not limited to, heart rate data, blood pressure data, temperature data, blood oxygen saturation level data, diet/nutrition information, medical reminders, health-related tips or information, or other health-related data. The associated monitoring device may be, for example, a tablet computing device, phone, personal digital assistant, computer, and the like.

In accordance with some embodiments, the electronic device can be configured in the form of a wearable electronic device that is configured or configurable to provide a wide range of functionality. As described above with respect to FIG. **2**, the wearable electronic device **100** may include a processing units **102** coupled with or in communication with a memory **104**, one or more communications channels **108**, output devices such as a display **120** and speaker **122**, one or more input components **106**, and other modules or components. An example wearable electronic device **100** may be configured to provide or calculate information regarding time, health information, biostatistics, and/or status to externally connected or communicating devices and/or software executing on such devices. The device **100** may also be configured to send and receive messages, video, operating commands, and other communications.

With reference to FIG. **16**, an example device **100** may include various sensors for measuring and collecting data that may be used to calculate a health metric or other health-related information. As one example, the wearable communication device can include an array of light sources **1611**-**1613** and a detector **1614** that are configured to function as an optical sensor or sensors. In one example, an optical sensor or sensors may implemented as a pairing of one or more light sources **1611**-**1613** and the detector **1614**. In one example implementation, the detector **1614** is configured to collect light and convert the collected light into an electrical sensor signal that corresponds to the amount of light incident on a surface of the detector **1614**. In one embodiment, the detector may be a photodetector, such as a photodiode. In other embodiments, the detector **1614** may include a phototube, photosensor, or other light-sensitive device.

In some cases, the one or more optical sensors may operate as a photoplethysmography (PPG) sensor or sensors. In some instances, a PPG sensor is configured to measure light and produce a sensor signal that can be used to estimate changes in the volume of a part of a user's body. In general, as light from the one or more light sources passes through the user's skin and into the underlying tissue, some light is reflected, some is scattered, and some light is absorbed, depending on what the light encounters. The light that is received by the detector **1614** may be used to generate a sensor signal, which may be used to estimate or compute a health metric or other physiological phenomena.

The light sources may operate at the same light wavelength range, or the light sources can operate at different light wavelength ranges. As one example, with two light sources, one light source may transmit light in the visible wavelength range while the other light source can emit light in the infrared wavelength range. In some cases, a modulation pattern or sequence may be used to turn the light sources on and off and sample or sense the reflected light. With reference to FIG. **16**, the first light source **1611** may include, for example, a green LED, which may be adapted for detecting blood perfusion in the body of the wearer. The second light source **1612** may include, for example, an infrared LED, which may be adapted to detect changes in water content or other properties of the body. The third **1613** light source may be a similar type or different types of LED element, depending on the sensing configuration.

The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics, including, without limitation, a heart rate, a respiration rate, blood oxygenation level,

a blood volume estimate, blood pressure, or a combination thereof. In some instances, blood may absorb light more than surrounding tissue, so less reflected light will be sensed by the detector of the PPG sensor when more blood is present. The user's blood volume increases and decreases with each heartbeat. Thus, in some cases, a PPG sensor may be configured to detect changes in blood volume based on the reflected light, and one or more physiological parameters of the user may be determined by analyzing the reflected light. Example physiological parameters include, but are not limited to, heart rate, respiration rate, blood hydration, oxygen saturation, blood pressure, perfusion, and others.

While FIG. **16** depicts one example embodiment, the number of light sources and/or detectors may vary in different embodiments. For example, another embodiment may use more than one detector. Another embodiment may also use fewer or more light sources than are depicted in the example of FIG. **16**. In particular, in the example depicted in FIG. **16**, the detector **1614** is shared between multiple light sources **1611-1613**. In one alternative embodiment, two detectors may be paired with two corresponding light sources to form two optical sensors. The two sensors (light source/detector pairs) may be operated in tandem and used to improve the reliability of the sensing operation. For example, output of the two detectors may be used to detect a pulse wave of fluid (e.g., blood) as it passes beneath the respective detectors. Having two sensor readings taken at different locations along the pulse wave may allow the device to compensate for noise created by, for example, movement of the user, stray light, and other effects.

In some implementation, one or more of the light sources **1611-1613** and the detector **1614** may also be used for optical data transfer with a base or other device. For example, the detector **1614** may be configured to detect light produced by an external mating device, which may be interpreted or translated into a digital signal. Similarly, one or more of the light sources **1611-1613** may be configured to transmit light that may be interpreted or translated into a digital signal by an external device.

Returning to FIG. **16**, the device **100** may also include one or more electrodes to measure electrical properties of the user's body. In this example, a first electrode **1601** and second electrode **1602** are disposed on the rear face of the device **100**. The first **1601** and second **1602** electrodes may be configured to make contact with the skin of the user's wrist when the device is being worn. As shown in FIG. **16**, a third electrode **1603** and fourth electrode **1604** may be disposed along a periphery of the device body **610**. In the configuration of FIG. **16**, the third **1603** and fourth **1604** electrodes are configured to come into contact with the skin of the user's other hand (that is not wearing the device **100**). For example, the third **1603** and fourth **1604** electrodes may be contacted when the user pinches the device **100** between two digits (e.g., a forefinger and thumb).

FIG. **16** depicts one example arrangement of electrodes. However, in other embodiments, one or more of the electrodes may be placed in locations that are different than the configuration of FIG. **16**. For example, one or more electrodes may be placed on a top surface or other surface of the device **100**. Additionally, fewer electrodes or more electrodes may be used to contact the user's skin, depending on the configuration.

Using the electrodes of the device, various electrical measurements may be taken, which may be used to compute a health metric or other health-related information. By way of example, the electrodes may be used to detect electrical activity of the user's body. In some cases, the electrodes may be configured to detect electrical activity produced by the heart of the user to measure heart function or produce an electrocardiograph (ECG). As another example, the electrodes of the device may be used to detect and measure conductance of the body. In some cases, the measured conductance may be used to compute a galvanic skin response (GSR), which may be indicative of the user's emotional state or other physiological condition. By way of further example, the electrodes may also be configured to measure other health characteristics, including, for example, a body fat estimate, body or blood hydration, and blood pressure.

In some embodiments, the optical sensors and electrodes discussed above with respect to FIG. **16** may be operatively coupled to sensing circuitry and the processing units **102** to define a health monitoring system. In this capacity, the processing units **102** may be any suitable type of processing device. In one embodiment, the processing units **102** include a digital signal processor. The processing units **102** may receive signals from the optical sensor(s) and/or electrodes and process the signals to correlate the signal values with a physiological parameter of the user. As one example, the processing units **102** can apply one or more demodulation operations to the signals received from the optical sensor. Additionally, the processing units **102** may control the modulation (i.e., turning on and off) of the light sources according to a given modulation pattern or sequence. The processing units **102** may also be used to calculate one or more biometrics or other heath related information.

In some implementations, the wearable electronic device may also receive sensor data or output from an external device. For example, an external mobile device having a global positioning system (GPS) may relay location information to the wearable device, which may be used to calibrate an activity metric, such as a pedometer or distance calculator. Similarly, sensor output of the wearable electronic device may be transmitted to an external device to compute health-related information. For example, output from an accelerometer in the wearable electronic device may be used determine a body position or gesture, which may be relayed to an external device and used to compute health-related information, such as activity level.

In some embodiments, some or all of the biosensors may be integrated into a module that is separate from and attached to the housing **601** of the device **100**. As described above with respect to FIG. **6**, in some embodiments, the biosensors are disposed relative to or attached to a rear cover **608** that is formed from an optically transparent material and is configured to be positioned with the opening of the housing **601**. In some embodiments, the rear cover **608** is disposed completely within the area of the cover so that the two components completely overlap when viewed from above. In some embodiments, the rear cover **608** has an edge that protrudes outwardly from the back surface of the housing **601**. In some embodiments, an edge of the rear cover **608** extends past a flat portion of the back surface of the housing **601**. The rear cover **608** may also have a convex, curved outer contour. The rear cover **608** may have a convex shape that is located within the center and surrounded by the edges of the rear cover **608**. The convex curved area of the rear cover **608** may include one or more windows or apertures that provide operational access to one or more internal components located within the housing. For example, the rear cover **608** may include an array of windows, each window including an aperture or opening for a respective light source **1611-1613** and/or the detector **1614**. In some embodiments, the windows have a curvature

that matches the curvature of the convex curved area of the rear cover **608**. In some embodiments, rear cover **608** includes a chamfered edge and a curved bottom surface, the windows being disposed within the curved surface. In some embodiments, two openings of the rear cover **608** are located along a first axis (e.g., an x-axis) and two openings are located along a second axis (e.g., a y-axis) that is transverse to the first axis.

5. Example Wireless Communications with External Devices

A wearable electronic device may include a functionality for performing wireless communications with an external device. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, the wireless communications are performed in accordance with a Near Field Communications (NFC) protocol. The communication may include an identification protocol and a secured data connection that can be used to identify the user, authorize activity, perform transactions, or conduct other aspects of electronic commerce.

FIG. **17** depicts an example system **1700** including a device **100** that is located proximate to a station **1710**. The station **1710** may include a variety of devices, including, without limitation, a payment kiosk, a vending machine, a security access point, a terminal device, or other similar device. In some cases, the station **1710** is incorporated into a larger system or device. For example, the station **1710** may be incorporated into a security gate of a building or a payment center for a vending system.

As shown in FIG. **17**, the device **100** is a wearable electronic device that may be placed proximate to the station **1710**. In this example, a second device **1720** is carried by a user, and may also be placed proximate to the station **1710**. In some embodiments, the device **100** and/or the second device **1720** includes a radio-frequency identification (RFID) system that is configured to enable one-way or two-way radio-frequency (RF) communications with the station **1710**. The one- or two-way communication may include an identification of the device **100** and the station **1710** to initiate a secured data connection between the two devices. The secured data connection may be used to authorize a transaction between the user and an entity that is associated with the station **1710**.

In some embodiments, the user may initiate a communication with the station **1710** by placing the device **100** near an active region on the station **1710**. In some implementations, the station **1710** is configured to automatically detect the presence of the device **100** and initiate an identification process or routine. The RFID system of the device may include a unique identifier or signature that may be used to authenticate the identity of the user. As previously mentioned, the identification process or routine may be used to establish a secure data connection between the device **100** and the station **1710**. The secure data connection may be used to authorize a purchase or download of data to or from the device **100**. In some cases, the secure data connection may be used to authorize the transfer of funds from a credit card or financial institution in exchange for a product that is associated with the station **1710**. Other transactions or forms of electronic commerce may also be performed using the wireless communication between the device **100** and the station **1710**.

6. Example Wireless Power System

As discussed above, a wearable electronic device may include an internal battery that is rechargeable using an external power source. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

One challenge associated with small devices is that it may be difficult to incorporate an electrical port for coupling the device to an external power source. Because wearable electronic devices have limited space for an external connector, it may be advantageous to electrically couple to a device without a cable or external connector. In at least some embodiments, the wearable electronic device described herein may be configured to operate as a receiver in a wireless power transfer system.

A wireless power transfer system, one example of which is an inductive power transfer system, typically includes a power-transmitting structure to transmit power and a power-receiving structure to receive power. In some examples, a power-receiving electronic device includes or otherwise incorporates an inductive power-receiving element configured to receive wireless power and/or charge one or more internal batteries. Similarly, a charging device may include or otherwise incorporate an indicative power-transmitting element configured to wirelessly transmit power to the power-receiving electronic device. The charging device may be configured as a base or dock on which the power-receiving electronic device rests or to which it physically connects in some embodiments. In other embodiments, the charging device may be proximate the electronic device but not necessarily touching or physically coupled.

In many examples, the battery-powered electronic device may be positioned on an external surface of the power-transmitting device, otherwise referred to as a dock. In these systems, an electromagnetic coil within the dock (e.g., transmit coil) may produce a time-varying electromagnetic flux to induce a current within an electromagnetic coil within the electronic device (e.g., receive coil). In many examples, the transmit coil may transmit power at a selected frequency or band of frequencies. In one example the transmit frequency is substantially fixed, although this is not required. For example, the transmit frequency may be adjusted to improve inductive power transfer efficiency for particular operational conditions. More particularly, a high transmit frequency may be selected if more power is required by the electronic device and a low transmit frequency may be selected if less power is required by the electronic device. In other examples, a transmit coil may produce a static electromagnetic field and may physically move, shift, or otherwise change its position to produce a spatially-varying electromagnetic flux to induce a current within the receive coil.

The electronic device may use the received current to replenish the charge of a rechargeable battery or to provide power to operating components associated with the electronic device. Thus, when the electronic device is positioned on the dock, the dock may wirelessly transmit power at a particular frequency via the transmit coil to the receive coil of the electronic device.

A transmit coil and receive coil may be disposed respectively within housings of the dock and electronic device so as to align along a mutual axis when the electronic device is placed on the dock. If misaligned, the power transfer efficiency between the transmit coil and the receive coil may

decrease as misalignment increases. Accordingly, in many examples, the wireless power transfer system may include one or more alignment assistance features to effect alignment of the transmit and receive coils along the mutual axis.

FIG. **18** depicts a front perspective view of an example wireless power transfer system **1800** in an unmated configuration. The illustrated embodiment shows an inductive power transmitter dock **1802** that is configured to couple to and wirelessly transmit power to an inductive power receiver accessory, in this case device **100**. The wireless power transfer system **1800** may include one or more alignment assistance features to effect alignment of the device **100** with the dock **1802** along a mutual axis. For example, the housings of the dock **1802** and the device **100** may assist with alignment. In one implementation, a portion of the housing of the device **100** may engage and/or interlock with a portion of the housing of the dock **1802** in order to effect the desired alignment. In some embodiments, a bottom portion of the device **100** may be substantially convex and a top surface of the dock **1802** may be substantially concave. In other examples, the interfacing surfaces of the dock **1802** and the device **100** may be substantially flat, or may include one or more additional housing features to assist with effecting mutual alignment.

In some embodiments, one or more actuators in the dock **1802** and/or device **100** can be used to align the transmitter and receiver devices. In yet another example, alignment assistance features, such as protrusions and corresponding indentations in the housings of the transmitter and receiver devices, may be used to align the transmitter and receiver devices. The design or configuration of the interface surfaces, one or more alignment assistance mechanisms, and one or more alignment features can be used individually or in various combinations thereof.

Alignment assistance can also be provided with one or more magnetic field sources. For example, a permanent magnet within the dock **1802** may attract a permanent magnet within the device **100**. In another example, a permanent magnet within the device **100** may be attracted by a magnetic field produced by the dock **1802**. In further examples, multiple alignment assistance features may cooperate to effect alignment of the transmit and receive coils. Power transfer efficiency may also decrease if the power consumption of the electronic device changes (e.g., the electronic device transitions from a trickle charge mode to constant current charge mode) during wireless power transfer.

As discussed previously with respect to FIG. **2**, the device **100** may include a processor coupled with or in communication with a memory, one or more communication interfaces, output devices such as displays and speakers, and one or more input devices such as buttons, dials, microphones, or touch-based interfaces. The communication interface(s) can provide electronic communications between the communications device and any external communication network, device or platform, such as, but not limited to, wireless interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. The device **100** may provide information regarding time, health, statuses or externally connected or communicating devices and/or software executing on such devices, messages, video, operating commands, and so forth (and may receive any of the foregoing from an external device), in addition to communications.

In the example depicted in FIG. **18**, the dock **1802** may be connected to an external power source, such as an alternating current power outlet, by power cord **1808**. In other embodiments, the dock **1802** may be battery operated. In still further examples, the dock **1802** may include a power cord **1808** in addition to an internal or external battery. Similarly, although the embodiment is shown with the power cord **1808** coupled to the housing of the dock **1802**, the power cord **1808** may be connected by any suitable means. For example, the power cord **1808** may be removable and may include a connector that is sized to fit within an aperture or receptacle opened within the housing of the dock **1802**.

Although the device **100** is shown in FIG. **18** as larger than the dock **1802**, the depicted scale may not be representative of all embodiments. For example, in some embodiments the dock **1802** may be larger than the device **100**. In still further embodiments the two may be substantially the same size and shape. In other embodiments, the dock **1802** and device **100** may take separate shapes.

FIG. **19** depicts a simplified block diagram of relevant aspects of the device **100** and dock **1802**. It may be appreciated that certain components of both the dock **1802** and device **100** are omitted from the figure for clarity. Likewise, the positions of the elements that are shown are meant to be illustrative rather than necessarily portraying a particular size, shape, scale, position, orientation, or relation to one another, although some embodiments may have elements with one or more of such factors as illustrated.

As described previously with respect to FIG. **2**, the device **100** may include one or more electronic components located within the housing **601**. For clarity, some of the components and modules described or depicted in various embodiments are omitted from the depiction of FIG. **19**. As shown in FIG. **19**, the device **100** may include an internal battery **114** that may be used to provide power to the various internal components of the device **100**. As described previously, the internal battery **114** may be rechargeable by an external power supply. In the present example, the internal battery **114** is operably connected to a receive coil **1869** via power conditioning circuit **1810**.

In the present example, the device **100** includes a receive coil **1869** having one or more windings for inductively coupling with a transmit coil **1832** of the dock **1802**. The receive coil **1869** may receive power wirelessly from the dock **1802** and may pass the received power to a battery **114** within the device **100** via power conditioning circuit **1810**. The power conditioning circuit **1810** may be configured to convert the alternating current received by the receive coil **1869** into direct current power for use by other components of the device. In one example, the processing units **102** may direct the power, via one or more routing circuits, to perform or coordinate one or more functions of the device **100** typically powered by the battery **114**.

As shown in FIG. **19**, the dock **1802** includes a transmit coil **1832** having one or more windings. The transmit coil **1832** may transmit power to the device **100** via electromagnetic induction or magnetic resonance. In many embodiments, the transmit coil **1832** may be shielded with a shield element that may be disposed or formed around portions of the transmit coil **1832**. Similarly, the receive coil **1869** may also include a shield element that may be disposed or formed around a portion of the receive coil **1869**.

As shown in FIG. **19**, the dock **1802** also includes a processor **1834** that may be used to control the operation of or coordinate one or more functions of the dock **1802**. In some embodiments, the dock **1802** may also include one or more sensors **1836** to determine whether the device **100** is

present and ready to receive transmitted power from the dock **1802**. For example, the dock **1802** may include an optical sensor, such as an infrared proximity sensor. When the device **100** is placed on the dock **1802**, the infrared proximity sensor may produce a signal that the processor **1834** uses to determine the presence of the device **100**. The processor **1834** may, optionally, use another method or structure to verify the presence of the electronic device via sensor **1836**. Examples of different sensors that may be suitable to detect or verify the presence of device **100** may include a mass sensor, a mechanical interlock, switch, button or the like, a Hall effect sensor, or other electronic sensor. Continuing the example, after the optical sensor reports that the device **100** may be present, the processor **1834** may activate a communication channel to attempt to communicate with the device **100**.

As illustrated in FIG. **19**, a bottom surface of the housing of the device **100** may partially contact a top surface of the dock housing. In some implementations, the interfacing surfaces of the device **100** and the dock **1802** may be formed with complementary geometries. For example, as depicted in FIG. **19**, the bottom surface of the device **100** is convex and the top surface of the dock **1802** is concave, following the same curvature as the bottom surface of the device **100**. In this manner, the complementary geometries may facilitate alignment of the electronic device and dock for efficient wireless power transfer.

In some embodiments, the dock **1802** and device **100** may include other alignment assistance features. For example the device **100** may include an alignment magnet **1838** which is positioned and oriented to attract a corresponding alignment magnet **1840** within the dock **1802**. In some cases, when the device **100** is positioned proximate the dock **1802**, the alignment magnets **1838**, **1840** may be mutually attracted, thereby affecting alignment of the portable electronic device **100** and the dock **1802** along a mutual axis. In other examples, the dock **1802** may include a ferromagnetic material in place of the alignment magnet **1840**. In these examples, the alignment magnet **1838** may be attracted to the ferromagnetic material. In still further cases, the receive coil **1869** or transmit coil **1832** may produce a static magnetic field that either attracts or repels either or both of the alignment magnets **1838**, **1840**.

As shown in FIG. **19**, the alignment magnets **1838**, **1840** may be positioned within a respective coil **1869**, **1832**. When the alignment magnets **1838**, **1840** are drawn together, the coils **1869**, **1832** may be placed into alignment. Additionally, the complementary geometries of the device **100** and the dock **1802** may further facilitate alignment when the alignment magnets **1838**, **1840** are drawn together.

7. Example Acoustic Module

As described above, the device may include one or more devices for transmitting and receiving acoustic energy. For the purposes of the following description of the acoustic module, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above. As previously discussed, in some embodiments, the device may include a speaker for transmitting acoustic energy and/or a microphone for receiving acoustic energy. For the purposes of the following description, a speaker device and a microphone are referred to generically as an acoustic module, which may be configured to transmit and/or receive acoustic energy depending on the particular implementation.

FIG. **20** depicts a simplified schematic cross-sectional view of a first embodiment of a device having an acoustic module **2006**. The representation depicted in FIG. **20** is not drawn to scale and may omit some elements for clarity. The acoustic module **2006** may represent either a portion of a speaker and/or microphone device described above with respect to the electronic device **100** of FIG. **2**.

As shown in FIG. **20**, an acoustic port **2020** may be formed in the housing **601** of the electronic device. In the present example, the acoustic port **2020** includes first and second orifices **2031**, **2032** that are formed in the housing **601** and acoustically couple the acoustic cavity **2011** of the acoustic module **2006** to the external environment (external to the electronic device). In the present embodiment, the first and second orifices **2031**, **2032** are offset with respect to the opening of the acoustic cavity **2011**. This configuration may help reduce the direct ingress of liquid **2001** into acoustic cavity **2011** of the acoustic module **2006** Also, as shown in FIG. **20** a shield **2021** or umbrella structure that is formed between the orifices **2031**, **2032** blocks the direct ingress of liquid **2001** into the acoustic cavity **2011**. As shown in FIG. **20**, the acoustic module **2006** also includes a screen element **2015** disposed at one end of the acoustic cavity **2011**, which may also prevent the ingress of liquid or other foreign debris into the acoustic cavity **2011**. The acoustic module **2006** also includes a seal **2016** disposed between the housing **601** and the connector element **2012** of the module, which may also be configured to prevent the ingress of water into the device and/or module.

In the present example depicted in FIG. **20**, the acoustic module **2006** may correspond to the speaker **122** described with respect to some embodiments. As shown in FIG. **20**, the acoustic module **2006** includes various components for producing and transmitting sound, including a diaphragm **2010**, a voice coil **2009**, a center magnet **2008**, and side magnets/coils **2007**. These components may cooperate to form a speaker acoustic element. In one implementation, the diaphragm **2010** is configured to produce sound waves or an acoustic signal in response to a stimulus signal in the center magnet **2008**. For example, a modulated stimulus signal in the center magnet **2008** causes movement of the voice coil **2009**, which is coupled to the diaphragm **2010**. Movement of the diaphragm **2010** creates the sound waves, which propagate through the acoustic cavity **2011** of acoustic module **2006** and eventually out the acoustic port **2020** to a region external to the device. In some cases, the acoustic cavity **2011** functions as an acoustical resonator having a shape and size that is configured to amplify and/or dampen sound waves produced by movement of the diaphragm **2010**.

As shown in FIG. **20**, the acoustic module **2006** also includes a yoke **2014**, support **2013**, connector element **2012**, and a cavity wall **2017**. These elements provide the physical support of the speaker elements. Additionally, the connector element **2012** and the cavity wall **2017** together form at least part of the acoustic cavity **2011**. The specific structural configuration of FIG. **20** is not intended to be limiting. For example, in alternative embodiments, the acoustic cavity may be formed from additional components or may be formed from a single component.

The acoustic module **2006** depicted in FIG. **20** is provided as one example of a type of speaker acoustic module. In other alternative implementations, the acoustic module may include different acoustic elements for producing and transmitting sound, including, for example, a vibrating membrane, piezoelectric transducer, vibrating ribbon, or the like. Additionally, in other alternative implementations, the

acoustic module may be a microphone acoustic module having one or more elements for converting acoustic energy into an electrical impulse. For example, the acoustic module may alternatively include a piezoelectric microphone acoustic element for producing a charge in response to acoustic energy or sound.

As previously mentioned, because the acoustic port **2020** connects the acoustic module **2006** to the external environment, there is a possibility that liquid may accumulate or infiltrate the interior of the module. In some cases, the screen element **2015** or other protective features may not prevent all liquid from entering the acoustic cavity **2011** of the module. For example, if the device is subjected to a liquid under pressure or a directed stream of liquid, some liquid ingress may occur. Additionally, naturally occurring moisture in the air may condense and accumulate over time resulting in the presence of liquid within the module. Thus, in some implementations, the acoustic module **2006** may include one or more elements configured to expel water or liquid that accumulates in, for example, the acoustic cavity **2011** of the module. The liquid expulsion process may include modifying the charge on a portion of the wall of the acoustic cavity **2011** to change the surface energy of the wall and/or producing an acoustic pulse using the diaphragm **2010** to help expel liquid from the acoustic cavity **2011**. In some embodiments, the screen **2015** may also have hydrophilic or hydrophobic properties that may facilitate removal of liquid held within the acoustic cavity **2011**.

8. Example Antenna and Cover

As previously described, a wearable electronic device may be configured to communicate wirelessly with various external devices and communication networks. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, as previously discussed with respect to FIG. **2**, the device may include one or more communication channels that are configured to transmit and receive data and/or signals over a wireless communications network or interface. Example wireless interfaces include radio frequency cellular interfaces, Bluetooth interfaces, Wi-Fi interfaces, or any other known communication interface.

In some implementations an antenna may be disposed with respect to the cover (e.g., crystal) of a device to facilitate wireless communications with an external device or communication network. In some cases, it may be advantageous to integrate an antenna into the cover to improve the transmission and reception of wireless signals from the device. In particular, the cover of the device may have dielectric properties that facilitate the transmission of radio frequency signals while also protecting the antenna from physical damage or interference. Additionally, if the antenna is integrated into a perimeter portion of the cover, the visual appearance or clarity of the cover may be minimized. Furthermore, the embodiments described below with respect to FIGS. **21**A-B may be used to integrate an antenna external to the housing, without increasing the thickness of the device body.

FIG. **21**A depicts a perspective exploded view of a cover **2100** and an antenna assembly **2130**. The cover **2100** depicted in FIG. **21**A is viewed from an inner surface **2124** that is configured to attach to or interface with the opening of the housing (described above with respect to FIG. **1**). As shown in FIG. **21**A, a groove **2128** may be formed within the inner surface **2124**. In this example, the groove **2128** is formed around the periphery of the cover **2100**. As mentioned previously, this may be advantageous in minimizing the visual impact of having the antenna assembly **2130** located within the cover **2100**.

As shown in FIG. **21**A the antenna assembly **2130** includes an antenna ring **2134** and a terminal **2140** which may interface with an electrical connector **2150**. In the present embodiment, the groove **2128** formed in the surface of the cover **2100** may be configured to accept the antenna ring **2134**. In particular, the groove **2128** may receive the entire antenna ring **2134** without a portion of the antenna ring **2134** protruding past the inner surface **2124**, when the antenna ring **2134** is installed. In some cases, the groove **2128** is formed to be a clearance or near clearance fit with the diameter of the antenna ring **2134**. Thus, in some cases, the antenna ring **2134** may substantially fill the groove **2128** when the ring is installed. In some cases, the groove **2128** may be configured to retain the antenna ring **2134** due to a slight interference fit or due to a feature formed within either the cover **2100** and/or the antenna assembly **2130**. In the present embodiment, the antenna assembly **2130** may be installed in the cover **2100** and then connected to other electronics via the terminal **2140** and the connector **2150**, which may protrude into an opening in the case or housing.

FIG. **21**B depicts a cross-sectional view of the cover and antenna at the connection point. In particular, FIG. **21**B depicts a detail cross-sectional view of the cover **2100** installed within the housing **601** at a region near the terminal **2140**. In this example, the cover **2100** is attached to a shelf of the housing **601** via a compressible element **2122**. The compressible element **2122** may provide a seal against water or other contaminates and also provide compliance between the cover **2100** and the housing **601**. The compressible element **2122** may be formed from a nitrile or silicone rubber and may also include an adhesive or other bonding agent.

As shown in FIG. **21**B, the antenna ring **2134** is disposed entirely within the groove **2128**. In this case, the antenna ring **2134** does not protrude past the inner surface **2124**. The antenna ring **2134** is electrically connected to the terminal **2140**, which protrudes into an opening in the housing **601**. As shown in FIG. **21**B, the terminal **2140** includes conductive pads **2142** for electrically connecting to the antenna ring **2134**. In this example, spring clips **2152** are configured to mechanically and electrically connect to the conductive pads **2142** on the terminal **2140**. One advantage to the configuration depicted in FIG. **21**B is that the antenna assembly **2130** may be installed in the cover **2100** before the cover **2100** is installed in the housing **601**. The terminal **2140** and connector **2150** facilitate a blind connection that may assist electrical connection as the cover **2100** is installed. Additionally, the configuration depicted in FIG. **21**B may allow for some movement between the cover **2100** and the housing **601** without disturbing the electrical connection with the antenna ring **2134**.

9. Example Haptic Module

As described above, the device may include one or more haptic modules for providing haptic feedback to the user. The embodiments described herein may relate to or take the form of durable and thin haptic feedback elements suitable to provide a perceivable single pulse haptic feedback. In general, a haptic device may be configured to produce a mechanical movement or vibration that may be transmitted through the housing and/or other component of the device. In some cases, the movement or vibration may be transmit-

ted to the skin of the user and perceived as a stimulus or haptic feedback by the user. In some implementations, the haptic feedback may be coupled to one or more device outputs to alert the user of an event or activity. For example, a haptic output may be produced in combination with an audio output produced by the speaker, and/or a visual output produced using the display.

The space constraints associated with a small wrist-worn device may present unique challenges to integrating a haptic mechanism into wearable electronics. In particular, a haptic mechanism may use a moving mass used to create the movement or vibration of the haptic output. The larger the mass that is moved, the easier it may be to create a perceivable stimulus using the haptic mechanism. However, a large moving mass and the supporting mechanism may be difficult to integrate into the compact space of, for example, the housing of a wearable electronic wristwatch.

Thus, the haptic module implemented in some embodiments may be configured to maximize the mechanical energy that is produced in a very compact form factor. FIGS. **22**A-B depict one example haptic mechanism that may be particularly well suited for use in a wearable electronic device. While the embodiment described with respect to FIGS. **22**A-B is provided as one example, the haptic module is not limited to this particular configuration.

FIG. **22**A depicts a three-quarters perspective view of a haptic device **112**, with a top, front and left sidewall of the housing **2220** removed to expose internal components. FIG. **22**B depicts a cross-sectional perspective view of the haptic device **112** cut in half to expose the internal components. In this example, a coil **2200** is used to induce movement of a frame **2260**, which houses a central magnet array **2210**. As shown in FIGS. **22**A-B, the movement of the frame **2260** is guided by a shaft **2250** that is fixed with respect to a housing **2220**.

In the present example, the coil **2200** may be energized by transmitting a current (e.g., from the battery) along a length of a wire that forms the coil **2200**. A direction of the current along the wire of the coil **2200** determines a direction of a magnetic field that emanates from the coil **2200**. In turn, the direction of the magnetic field determines a direction of movement of the frame **2260** housing the central magnet array **2210**. One or more springs may bias the frame **2260** towards the middle region of the travel. In this example, the frame **2260** and central magnet array **2210**, through operation of the coil **2200**, function as a moving mass, which generates a tap or vibration. The output of the haptic device **112**, created by the moving mass of the frame **2260** and central magnet array **2210**, may be perceived as a haptic feedback or stimulus to the user wearing the device.

For example, when the coil **2200** is energized, the coil **2200** may generate a magnetic field. The opposing polarities of the magnets in the magnet array **2210** generates a radial magnetic field that interacts with the magnetic field of the coil **2200**. The Lorentz force resulting from the interaction of the magnetic fields causes the frame **2260** to move along the shaft **2250** in a first direction. Reversing current flow through the coil **2200** reverses the Lorentz force. As a result, the magnetic field or force on the central magnet array **2210** is also reversed and the frame **2260** may move in a second direction. Thus, frame **2260** may move in both directions along the shaft **2250**, depending on the direction of current flow through the coil **2200**.

As shown in FIG. **22**A, the coil **2200** encircles the central magnet array **2210**, which is disposed near the center of the frame **2260**. As previously described, the coil **2200** may be energized by transmitting a current along the length of the wire forming the coil **2200**, and the direction of the current flow determines the direction of the magnetic flux emanating from the coil **2200** in response to the current. Passing an alternating current through the coil **2200** may cause the central magnet array **2210** (and frame **2260**) to move back and forth along a shaft **2250**. In order to prevent the central magnet array **2210** from being attracted to the shaft **2250**, which could increase friction between the two and thereby increase the force necessary to move the central magnet array **2210** and frame **2260**, the shaft **2250** may be formed from a non-ferrous material such as tungsten, titanium, stainless steel, or the like.

As depicted in FIGS. **22**A-B, the coil **2200** is positioned within a frame **2260** that holds the central magnet array **2210**, but is not affixed to the coil **2200**. Rather, an air gap separates the coil **2200** from the central magnet array **2210** and the frame **2260** is free to move with respect to the coil **2200**, which is generally stationary. Further, the frame **2260** generally moves with the central magnet array **2210**. As illustrated in FIGS. **22**A-B, the frame **2260** may have an aperture formed therein of sufficient size to contain the coil **2200**. Even when the frame and central magnet array are maximally displaced within the housing **2220** (e.g., to one end or the other of the shaft **2250**), the coil **2200** does not contact any portion of the frame **2260**. It should be appreciated that the coil **2200** remains stationary in the housing **2220** while the frame **2260** and central magnet array **2210** move, although in other embodiments the coil **2200** may move instead of, or in addition to, the frame and/or central magnet array. However, by keeping the coil **2200** stationary, it may be easier to provide interconnections for the coil, such as between the coil and the flex, and therefore reduce the complexity of manufacture.

As shown in FIGS. **22**A-B, the central magnet array **2210** may be formed from at least two magnets **2211**, **2212** of opposing polarities. A center interface **2270** may be formed from a ferrous or non-ferrous material, depending on the embodiment. A ferrous material for the center interface **2270** may enhance the overall magnetic field generated by the central magnet array **2210**, while a non-ferrous material may provide at least a portion of a return path for magnetic flux and thus assist in localizing the flux within the housing **2220**. In some embodiments, the magnets **2211**, **2212** are formed from neodymium while the frame is tungsten. This combination may provide a strong magnetic field and a dense mass, thereby yielding a high weight per volume structure that may be used as the moving part of the haptic device **112**.

10. Example Crown Module

As described above, the device may include a crown that may be used to accept user input to the device. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a crown may be used to accept rotary input from the user, which may be used to control aspects of the device. The crown may be knurled or otherwise textured to improve grip with the user's finger and/or thumb. In some embodiments, a crown may be turned by the user to scroll a display or select from a range of values. In other embodiments, the crown may be rotated to move a cursor or other type of selection mechanism from a first displayed location to a second displayed location in order to select an icon or move the selection mechanism between various icons that are output on the display. In a time

keeping application, the crown may also be used to adjust the position of watch hands or index digits displayed on the display of the device. The crown may also be used to control the volume of a speaker, the brightness of the display screen, or control other hardware settings.

In some embodiments, the crown may also be configured to accept linear, as well as rotary, input. For example, the crown may be configured to translate along an axis when pressed or pulled by the user. In some cases, the linear actuation may be used as additional user input. The actuation may provide a binary output (actuated/not actuated) or may also provide a non-binary output that corresponds to the amount of translation along the axis of motion. In some instances, the linear input to the crown may be combined with the rotary input to control an aspect of the device.

The embodiments described herein may be used for at least a portion of the crown module integrated into a wearable electronic device. The embodiments are provided as examples and may not include all of the components or elements used in a particular implementation. Additionally, the crown module is not intended to be limited to the specific examples described below and may vary in some aspects depending on the implementation.

In some embodiments, an optical encoder may be used to detect the rotational motion of the crown. More specifically, the example provided below with respect to FIG. **23** may use an optical encoder to detect rotational movement, rotational direction and/or rotational speed of a component of the electronic device. Once the rotational movement, rotational direction and/or rotational speed have been determined, this information may be used to output or change information and images that are presented on a display or user interface of the electronic device.

Integrating an optical encoder into the space constraints of a typical wearable electronic device may be particularly challenging. Specifically, some traditional encoder configurations may be too large or delicate for use in a portable electronic device. The optical encoder described below may provide certain advantages over some traditional encoder configurations and may be particularly well suited for use with a crown module of a wearable electronic device.

As shown in the example embodiment of FIG. **23**, the optical encoder of the present disclosure includes a light source **2370**, a photodiode array **2380**, and a shaft **2360**. However, unlike typical optical encoders, the optical encoder of the present disclosure utilizes an encoding pattern disposed directly on the shaft **2360**. For example, the encoding pattern includes a number of light and dark markings or stripes that are axially disposed along the shaft **2360**. Each stripe or combination of stripes on the shaft **2360** may be used to identify a position of the shaft **2360**. For example, as light is emitted from the light source **2370** and reflected off of the shaft **2360** into the photodiode array **2380**, a position, rotation, rotation direction and rotation speed of the shaft **2360** may be determined. Once the rotation direction and speed are determined, this information may be used to output or change information or images that are presented on the display or user interface of the electronic device.

In other embodiments, the shape or form of the shaft of the encoder may be used to determine a position, rotation, rotation direction and rotation speed of the shaft. For example, the shaft may be fluted or have a number of channels that cause the light to be reflected in a number of different directions. Accordingly, a diffractive pattern may be used to determine the rotation, rotation direction and rotation speed of the shaft.

FIG. **23** illustrates a simplified depiction of the device **100** and crown module **642** in accordance with some embodiments. As shown in FIG. **23**, the crown module **642** may be integrated with the housing **601** of the device **100** and may be formed from a dial **2340** disposed at the end of a shaft **2360**. In the present embodiment, the crown module **642** also forms part of the optical encoder. As discussed above, the crown module **642** includes an optical encoder that includes a shaft **2360**, a light source **2370**, and a photodiode array **2380**. Although a photodiode array is specifically mentioned, embodiments disclosed herein may use various types of sensors that are arranged in various configurations for detecting the movement described herein. For example, the movement of the shaft **2360** may be detected by an image sensor, a light sensor such as a CMOS light sensor or imager, a photovoltaic cell or system, photo resistive component, a laser scanner and the like.

The optical encoder may produce an encoder output that is used to determine positional data of the crown module **642**. In particular, the optical encoder may produce an output that is used to detect that movement of the dial **2340** including the direction of the movement, speed of the movement and so on. The movement may be rotational movement, translational movement, angular movement, and so on. The optical encoder may also be used to detect the degree of the change of rotation of the dial **2340** and/or the angle of rotation of the dial **2340** as well as the speed and the direction of the rotation of the dial **2340**.

The signals or output of the optical encoder may be used to control various aspects of other components or modules of the device. For example, continuing with the time keeping application example discussed above, the dial **2340** may be rotated in a clockwise manner in order to advance the displayed time forward. In one implementation, the optical encoder may be used to detect the rotational movement of the dial **2340**, the direction of the movement, and the speed at which the dial **2340** is being rotated. Using the output from the optical encoder, the displayed hands of a time keeping application may rotate or otherwise move in accordance with the user-provided rotational input.

Referring back to FIG. **23**, the crown module **642** may be formed from dial **2340** that is coupled to the shaft **2360**. In some cases, the shaft **2360** and dial **2340** may be formed as a single piece. As the shaft **2360** is coupled to, or is otherwise a part of the dial **2340**, as the dial **2340** rotates or moves in a particular direction and at a particular speed, the shaft **2360** also rotates or moves in the same direction and with the same speed.

As shown in FIG. **23**, the shaft **2360** of the optical encoder includes an encoding pattern **2365**. As discussed above, the encoding pattern **2365** may be used to determine positional information about the shaft **2360** including rotational movement, angular displacement and movement speed. As shown in FIG. **23**, the encoding pattern **2365** may include a plurality of light and dark stripes.

Although light stripes and dark stripes are specifically mentioned and shown, the encoding pattern **2365** may consist of various types of stripes having various shades or colors that provide surface contrasts. For example, the encoding pattern **2365** may include a stripe or marking that has a high reflective surface and another stripe that has a low reflective surface regardless of the color or shading of the stripes or markings. In another embodiment, a first stripe of the encoding pattern **2365** may cause specular reflection while a second stripe of the encoding pattern **2365** may cause diffuse reflection. When the reflected light is received by the photodiode array **2380**, a determination may be made

as to the position and movement of the shaft such as described below. In embodiments where a holographic or diffractive pattern is used, the light from the light source **2370** may diffract from the shaft **2360**. Based on the diffracted light, the photodiode array **2380** may determine the position, movement and direction of movement of the shaft **2360**.

In some embodiments, the stripes of the encoding pattern **2365** extend axially along the shaft **2360**. The stripes may extend along the entire length of the shaft **2360** or partially along a length of the shaft **2360**. In addition, the encoding pattern **2365** may also be disposed around the entire circumference of the shaft **2360**. In other embodiments, the encoding pattern **2365** may include a radial component. In yet other embodiments, the encoding pattern **2365** may have both a radial component and an axial component.

In some embodiments, the crown module may also include a tactile switch for accepting translational input from the user. FIGS. **24**A-B depict another example of a crown module **642***a* having a tactile switch assembly **2410**. As shown in FIG. **24**A, the tactile switch assembly **2410** may include a dial **2448** (or button), a coupling **2418**, a shear plate **2456**, and a tactile switch **2414**.

In the embodiment depicted in FIGS. **24**A-B, the dial **2448** is translatable and/or rotatable relative to the housing. The ability of the dial **2448** to translate and rotate relative to the housing allows a user to provide a rotational force and/or translating force to the tactile switch assembly. In particular, the dial **2448** of the present example may be operably coupled to or form part of an optical encoder, in accordance with the example described above with respect to FIG. **23**.

In the present example, the dial **2448** includes an outer surface **2432** that is configured to receive a rotary or rotational user input and a stem **2450** that extends from an interior surface **2434** of the dial **2448**. The stem **2450** may define a coupling aperture that extends longitudinally along a length or a portion of a length of the stem **2450**. In the depicted example, the stem **2450** may be hollow or partially hollow.

In the example depicted in FIGS. **24**A-B, the coupling **2418** may be a linkage, such as a shaft, that couples the dial **2448** to the tactile switch **2414**. The coupling **2418** may be integrally formed with the dial **2448** or may be a separate component operably connected thereto. For example, the stem **2450** of the dial **2448** may form the coupling member that is integrally formed with the dial **2448**. The coupling **2418** may be made of a conductive material, such as one or more metals or metal alloys. Due to the conductive characteristics, the coupling **2418** may further act to electrically couple the dial **2448** to the tactile switch **2414** and shear plate **2456**. In the example depicted in FIGS. **24**A-B, the shear plate **2456** is positioned between the coupling **2418** and the tactile switch **2414**. In some embodiments, the shear plate **2456** may prevent or reduce shearing forces from the coupling from being transmitted to the tactile switch. The shear plate **2456** also allows transfer of linear force input from the dial **2448** to the switch **2414**.

The configuration depicted in FIGS. **24**A-B may be used to accept both rotational and translational input from the user. For example, if a user provides a rotational force to the dial **2448**, the coupling **2418** and dial **2448** may rotate in the direction of the force. The coupling **2418** may be attached to or integrated with one or more sensors that are configured to detect rotational movement. For example the coupling **2418** may be integrated with an optical encoder, similar to the example described above with respect to FIG. **23**. Additionally, if a user provides a translational force to the dial **2448**, the force may be transmitted through the dial **2448** and coupling **2418** to actuate the switch **2414**. In some cases, the switch **2414** includes a metal dome switch that is configured to provide a tactile feedback when actuated. In some cases, the actuation of a dome switch may be perceived by the user as a click or release as the switch **2414** is actuated. Once the force has been removed from the dial **2448**, the dome switch resiliently returns to its original position, providing a biasing force against the coupling **2418** to return both the dial **2448** and the coupling **2418** to their original positions. In some embodiments, the tactile switch **2414** may include a separate biasing element, such as a spring, that exerts a force (either directly or indirectly via the shear plate) against the coupling. FIG. **24**A depicts the tactile switch assembly **2410** when there is no force applied (un-actuated). FIG. **24**B depicts the tactile switch assembly **2410** when there is a translational force applied to the dial **2448** (actuated).

11. Example Band Attachment Mechanism

For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

As described above, a wearable electronic device may include a band that is attached to a device body having one or more receiving features. In particular, the housing may include or form a receiving feature that facilitates an interchange or replacement of different bands that are used to secure the device to the wrist of the user. By replacing or interchanging bands the device may be adapted for multiple uses ranging from sporting activities to professional or social activities.

In some embodiments, the receiving features are configured to be operated without the use of special tools or fixtures. For example, the bands may be interchanged by hand or with the help of a simple tool, such as a pointed object. Additionally or alternatively, a tool or other component, such as a component of the device to which the attachment system is coupled, may be configured to actuate a button or other component of the attachment system to secure and/or release the band from the device. In one embodiment, the lug portion of a band may be configured to be inserted into an opening or channel portion of the receiving feature. Once the lug of the band has been inserted into the opening, the lug may slide within the opening of the device until the band is secured or otherwise coupled to the device. The coupling between the band and the receiving feature may provide a secure attachment of the band to the housing or device body. Just as the band is configured to slide into the channel of the receiving feature, the lug may also slide out of the channel of the receiving feature allowing the band to be detached from the device body.

In one embodiment, the receiving feature includes a locking mechanism, which may be integrated with portions of either the band or the receiving feature. In one example, as the band is inserted into a receiving feature of the device, the locking mechanism interfaces with a portion of the receiving feature to lock or otherwise secure the band within the receiving feature. The locking mechanism may also be configured to interface with a releasing mechanism associated with the receiving feature. For example, a releasing mechanism may be configured to disengage or release the locking mechanism. In some implementations. actuation of the releasing mechanism causes the locking mechanism to be released and allows the band to be removed by sliding within the receiving feature.

FIG. **25**A depicts a receiving feature and band assembly as viewed from the bottom of the device body. As shown in FIG. **25**A, a receiving feature **623***a* includes an opening or channel **2501** that is formed into the body or housing of the device. The channel **2501** is configured to receive the lug **2510** attached to an end of the band strap **621***a*. The receiving feature **623***a* may also include a locking mechanism **2530** that is configured to maintain the band strap **621***a* within the channel **2501** once it has been installed. As discussed above, the locking mechanism **2530** may be releasable by the user, which may facilitate band replacement. In this example, the locking mechanism **2530** includes a spring-loaded retaining mechanism that engages the lug **2510** to retain the lug **2510** in the channel **2501** and maintain the attachment of the band strap **621***a* to the device. As shown in FIG. **25**A, the locking mechanism **2530** also includes a button located on the bottom of the housing that may be depressed by the user to release the locking mechanism and allow the lug **2510** and the band strap **621***a* to be removed from the channel **2501**. In the present example, the button of the locking mechanism **2530** is located on a curved portion of the case or housing. In some embodiments, the button of the locking mechanism **2530** is located along the centerline of the case or housing.

In some embodiments, the opening or channel **2501** of the receiving feature **623***a* includes a port or connector for receiving a mating electrical component. In some embodiments, the connector or port is covered by a label or sticker so that the inside surface of the opening or channel **2501** appears continuous. The connector or port may be located along the vertical centerline of the case or housing.

FIG. **25**B depicts an example exploded view of the receiving feature **623***a* and the lug **2510** of the band strap **621***a*. As shown in FIG. **25**B, the band strap **621***a* may be formed from a separate part and attached to lug **2510** via a pivot or other type of joint. In other embodiments, the band strap **621***a* may have an end feature that is integrally formed as part of the band strap **621***a*. As also shown in FIG. **25**B, the lug **2510** may be attached to the receiving feature **623***a* by aligning the axis of the lug **2510** with the axis of the channel **2501** and then sliding the lug **2510** into the channel **2501**.

FIG. **25**C depicts an example assembly sequence of the lug **2510** being inserted into the channel **2501** of the receiving feature **623***a*. As shown in FIG. **25**C, the lug **2510** may be positioned along the side of the receiving feature **623***a* having the lug **2510** approximately aligned with the channel **2501** of the receiving feature **623***a*. The lug **2510** (and band strap **621***a*) may then be inserted into the channel **2501** of the receiving feature **623***a* by sliding the lug **2510** along the length of the channel **2501**. Once the lug **2510** is approximately centered in the channel **2501** of the receiving feature **623***a*, the locking mechanism **2530** or other securing feature may engage, thereby retaining the lug **2510** (and band strap **621***a*) within the channel **2501**. As previously discussed, the lug **2510** (and band strap **621***a*) may be removed from the receiving feature **623***a* by depressing the button of the locking mechanism **2530**, which may disengage the lock and allow movement of the lug **2510** within the channel **2501**.

The example described above is provided with respect to one example embodiment. The geometry of the end of the band strap and/or the geometry of the channel may vary depending on the implementation. Additionally, the engagement mechanism may vary depending on the design of the band strap and the device body. The geometry or layout of the features may vary and remain within the scope of the present disclosure. Additionally, while the examples provided above are described with respect to attaching a band strap to a device body, the receiving feature (**623***a*) may be used to attach a variety of other parts to the device body. For example a lanyard, cable, or other accessory may be attached to the device body using the receiving feature and other similar features.

12. Example Bands

As described above, a wearable electronic device may include a band that is used to secure the device to the wrist of a user. In some embodiments, the band may be formed from two band straps that are attached to the housing of the device body. The band straps may be secured around the wrist of a user by a clasp or latching mechanism. As also described above, the device may be configured to facilitate replacement of the band. This feature may allow the use of a variety of types of bands, which may adapt the device for multiple uses ranging from sporting activities to professional or social activities.

In some cases, the band may be formed from a woven textile material. In one example, the band is formed from a woven material that includes one or more strands or threads formed from a natural or synthetic material. The woven material may be formed, for example, from a plurality of warp threads that are woven around one or more weft threads. More specifically, the woven material may include a plurality of warp threads disposed along the length of the band, and at least one weft thread positioned perpendicular to, and coupled to, woven or interlaced between the plurality of warp threads. In some cases, the plurality of warp threads may run the entire length of the woven portion of the band strap. Additionally, in some cases, the at least one weft thread may include a single thread that may be continuously woven between the plurality of warp threads or, alternatively, may include a plurality of threads that may be woven between the plurality of warp threads. A weft thread that is woven between a plurality of warp threads may form consecutive cross-layers with respect to the plurality warp threads in order to form the band.

In some cases, one or more of the strands or threads may be a metallic or conductive material. This may improve the strength of the band and may also facilitate coupling with magnetic elements, such as a metallic clasp. In some cases, other elements may be woven into the band, including, for example, product identifying elements, decorative elements, or functional components.

In other embodiments, the band may be formed from a metallic mesh material. In one example, the metallic mesh is formed from an array of links that are interlocked to form a sheet of fabric. Some or all of the links in the mesh may be formed from a ferromagnetic material, which may facilitate magnetic engagement with a magnetic clasp. In some cases, each link of the mesh is formed from a section of metallic filament that is bent or formed into a closed shape. Each closed shape may be interlocked with one or more adjacent links to form a portion of the sheet or fabric. In some cases, a metallic filament is formed around a series of rods or pins that are disposed at a regular spacing within the mesh. In some cases, one or more strands or filaments that may be formed from a ferromagnetic material are woven or integrated with the links of the mesh.

In other examples, the band may be formed from a sheet of material. For example, the band may be formed from a synthetic leather, leather, or other animal hide. Additionally or alternatively, the band may be formed from a polymer material, an elastomer material, or other type of plastic or synthetic. In some cases, the band is formed from a silicone sheet material.

The clasp that is used to attach the free ends of the band straps may vary depending on the material that is used and the construction of the band. For example, as mentioned above, a metallic mesh material may use a metallic clasp to join the ends of the band. Additionally, a leather band may be integrated with magnetic and/or ferromagnetic components and may include a magnetic clasp. In some embodiments, the free ends of the band straps are secured using a buckle or tang on a first band strap that is configured to interface with a hole or aperture in a second band strap. A variety of other clasp configurations may also be used.

13. Example Display

For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above. As described above, the device includes a display disposed within the housing or enclosure. The device may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user, including, for example, a graphical user interface, notifications, health statistics, and the like. In some cases, the display may be configured to present the current time and date similar to a traditional watch or timepiece.

In some embodiments, the display is formed from an organic light emitting diode (OLED) display element. An active region of the display may include an array of light-emitting display pixels **2604** such as array **2602**, shown in FIG. **26**. Pixels **2604** may be arranged in rows and columns in array **2602** and may be controlled using a pattern of control lines. Each pixel may include a light-emitting element such as organic light-emitting diode **2612** and associated control circuitry **2610**. Control circuitry **2610** may be coupled to the data lines **2606** and gate lines **2608** so that control signals may be received from driver circuitry, which may be implemented as an integrated circuit. Although described as an OLED display, certain embodiments may implement other display technology, such as LCD displays and the like.

To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device **100**, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device **100** may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein

Although the disclosure above is described in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments but instead defined by the claims herein presented.

I claim:

1. An electronic device, comprising:

a housing defining a first opening opposite to a second opening;

a band attached to the housing and configured to secure the electronic device to a user;

a display positioned in the first opening;

a ceramic cover disposed over the second opening and forming a portion of an exterior surface of the electronic device;

a biosensor module disposed within the second opening below the ceramic cover; and

a wireless charging receive coil aligned with the second opening and below the ceramic cover;

wherein:

the ceramic cover is configured to pass optical signals generated by the biosensor module; and

the ceramic cover is configured to pass wireless power from an external wireless charging device to the wireless charging receive coil.

2. The electronic device of claim **1**, wherein the biosensor module comprises:

a light source configured to emit light toward a region of skin of the user; and

a detector configured to receive light reflected from the region of skin.

3. The electronic device of claim **2**, wherein:

the ceramic cover defines a first opening to transmit the light from the light source; and

the ceramic cover defines a second opening to receive the light reflected from the region of skin.

4. The electronic device of claim **2**, wherein:

the light source and the detector are configured to measure changes in light absorption by the region of skin;

the electronic device is configured to compute a health metric using the measured change in light absorption; and

the display is configured to display information associated with the health metric.

5. The electronic device of claim **2**, wherein the light source and the detectors are configured to operate as a photoplethysmogram (PPG) sensor.

6. The electronic device of claim **1**, wherein:

the ceramic cover is a disk having a disk diameter that is greater than an opening diameter of the second opening; and

the ceramic cover forms a water-tight seal with the housing along a perimeter of the ceramic cover.

7. The electronic device of claim **1**, wherein:

the second opening has an opening diameter;

the wireless charging receive coil has a coil diameter that is less than the opening diameter; and

the wireless charging receive coil is configured to receive the wireless power through the second opening.

8. The electronic device of claim **1**, wherein:

the ceramic cover has a convex contoured shape that protrudes toward the user; and

the convex contoured shape facilitates alignment between the ceramic cover and a mating surface of the external wireless charging device.

9. A wearable electronic device, comprising:

a housing comprising a bottom portion defining an opening;

a biosensor module aligned with the opening;

a wireless charging receive coil positioned within the housing and aligned with the opening;

a battery operably coupled to the wireless charging receive coil; and

a cover disposed over the biosensor module; wherein:

the cover is configured to pass optical signals to and from the biosensor module; and

the cover is configured to pass wireless power to the wireless charging receive coil.

10. The wearable electronic device of claim **9**, wherein:

the housing is formed from a metal material; and

the cover is formed from a non-metal material.

11. The wearable electronic device of claim **9**, wherein:

the wireless charging receive coil has a coil diameter that is less than a diameter of the biosensor module; and

the wireless charging receive coil is configured to receive the wireless power through the biosensor module.

12. The wearable electronic device of claim **9**, wherein:

the cover is a disk having a convex shape that protrudes away from the housing; and

the convex shape is configured to facilitate alignment with a concave surface of an external inductive power transmitter dock.

13. The wearable electronic device of claim **12**, wherein:

the wearable electronic device is magnetically coupled to the external inductive power transmitter dock through the cover and the biosensor module.

14. The wearable electronic device of claim **9**, wherein:

the biosensor module includes an array of optical components; and

the cover includes an array of windows, each window aligned with a corresponding optical component of the array of optical components.

15. An electronic watch, comprising:

a housing defining an interior cavity and a bottom portion having an opening;

a band attached to the housing and configured to secure the electronic watch to a user;

a biosensor module positioned along the bottom portion of the housing and configured to transmit optical signals and receive reflected optical signals through the opening of the housing; and

a wireless charging receive coil positioned within the interior cavity and configured to receive wireless power through the opening of the housing.

16. The electronic watch of claim **15**, wherein:

the wireless charging receive coil is configured to receive power from an external inductive power transmitter dock; and

the electronic watch is configured to magnetically couple with the external inductive power transmitter dock.

17. The electronic watch of claim **15**, wherein:

the wireless charging receive coil is configured to receive power from an external inductive power transmitter dock;

the electronic watch defines a convex contoured surface along the bottom portion; and

the convex contoured surface is configured to facilitate alignment with a concave contoured surface of the external inductive power transmitter dock.

18. The electronic watch of claim **17**, wherein the convex contoured surface is configured to protrude toward a portion of skin of the user when the electronic watch is worn.

19. The electronic watch of claim **15**, wherein:

the electronic watch is configured to compute a health metric using the biosensor module; and

the health metric is one or more of: a heart rate, a respiration rate, a blood oxygenation level, a blood volume estimate, or blood pressure.

20. The electronic watch of claim **19**, wherein:

the electronic watch includes a display; and

the display is configured to display information associated with the health metric.

* * * * *

EXHIBIT C

US010942491B2

(12) **United States Patent**
Rothkopf et al.

(10) **Patent No.: US 10,942,491 B2**
(45) **Date of Patent: Mar. 9, 2021**

(54) **WEARABLE ELECTRONIC DEVICE**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/826,130**

(22) Filed: **Mar. 20, 2020**

(65) **Prior Publication Data**

US 2020/0233380 A1 Jul. 23, 2020

Related U.S. Application Data

(63) Continuation of application No. 15/261,917, filed on Sep. 10, 2016, now Pat. No. 10,627,783, and a (Continued)

(51) **Int. Cl.**
G04G 17/02 (2006.01)
A61B 5/0295 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .... ***G04G 17/02*** (2013.01); ***A61B 5/0205*** (2013.01); ***A61B 5/0261*** (2013.01); (Continued)

(58) **Field of Classification Search**
None
See application file for complete search history.

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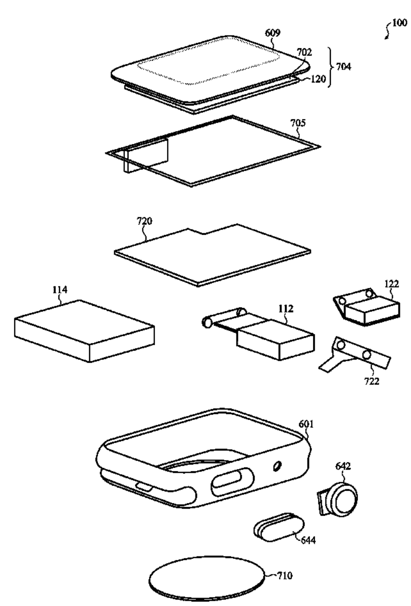
(57) **ABSTRACT**

A consumer product that is a portable and, in some cases, a wearable electronic device. The wearable electronic device may have functionalities including: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating with other electronic devices or services; visually depicting data on a display; gather data form one or more sensors that may be used to initiate, control, or modify operations of the device; determine a location of a touch on a surface of the device and/or an amount of force exerted on the device, and use either or both as input.

19 Claims, 26 Drawing Sheets



Related U.S. Application Data

continuation of application No. 15/261,912, filed on Sep. 10, 2016, now Pat. No. 10,620,591, and a continuation of application No. 15/261,914, filed on Sep. 10, 2016, now Pat. No. 10,613,485, and a continuation of application No. 14/842,617, filed on Sep. 1, 2015, now Pat. No. 10,599,101.

(60) Provisional application No. 62/044,974, filed on Sep. 2, 2014.

(51) **Int. Cl.**

G06F 1/16	(2006.01)
G06F 3/01	(2006.01)
G04G 21/02	(2010.01)
G04B 39/02	(2006.01)
A61B 5/00	(2006.01)
A61B 5/1455	(2006.01)
A61B 5/0205	(2006.01)
A61B 5/026	(2006.01)
G04B 3/04	(2006.01)
G04G 13/00	(2006.01)
A61B 5/024	(2006.01)
A61B 5/08	(2006.01)

(52) **U.S. Cl.**
CPC ***A61B 5/0295*** (2013.01); ***A61B 5/14551*** (2013.01); ***A61B 5/681*** (2013.01); ***G04B 39/02*** (2013.01); ***G04G 21/025*** (2013.01); ***G06F 1/163*** (2013.01); ***G06F 1/169*** (2013.01); ***G06F 1/1643*** (2013.01); ***G06F 3/015*** (2013.01); ***G06F 3/016*** (2013.01); *A61B 5/02427* (2013.01); *A61B 5/02438* (2013.01); *A61B 5/0816* (2013.01); *A61B 5/14552* (2013.01); *G04B 3/04* (2013.01); *G04G 13/00* (2013.01)

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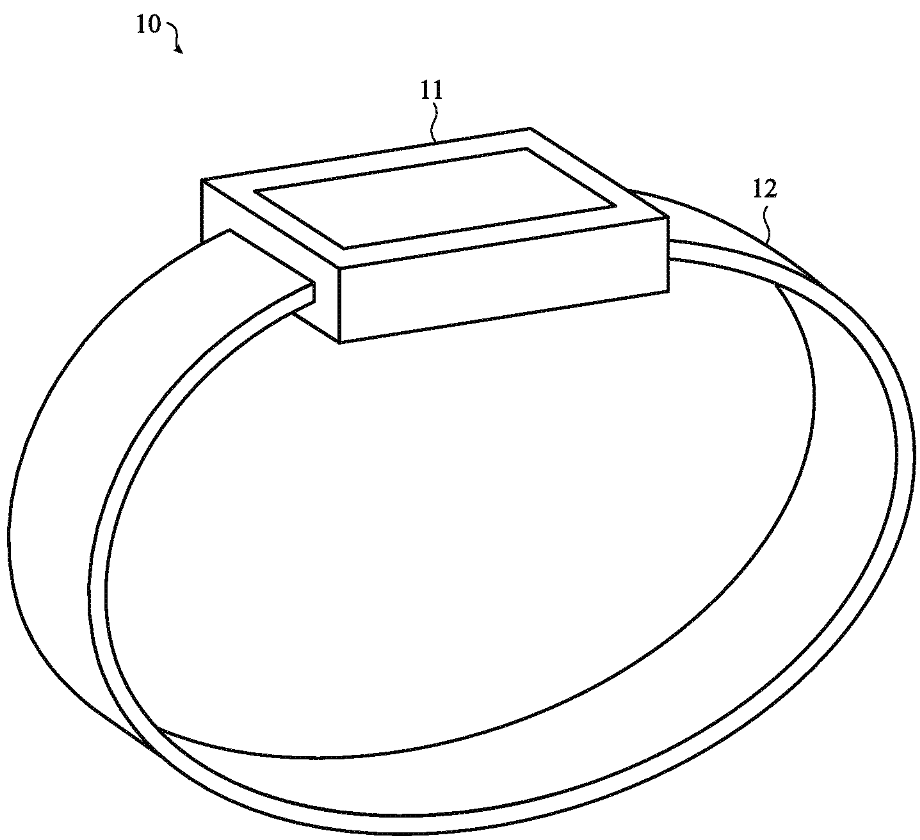
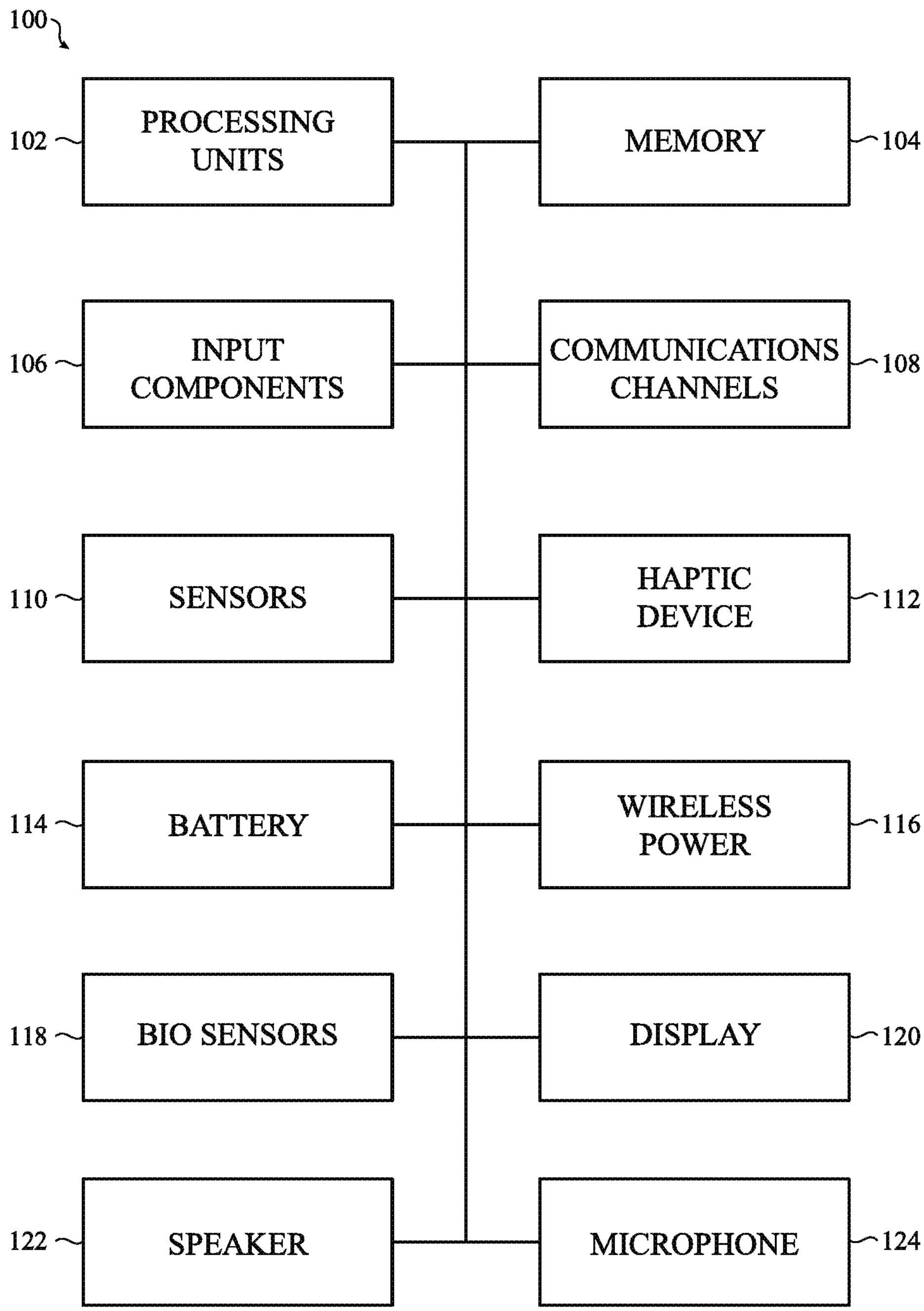


FIG. 1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INPUT COMPONENTS
COMMUNICATIONS CHANNELS
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SENSORS
HAPTIC DEVICE
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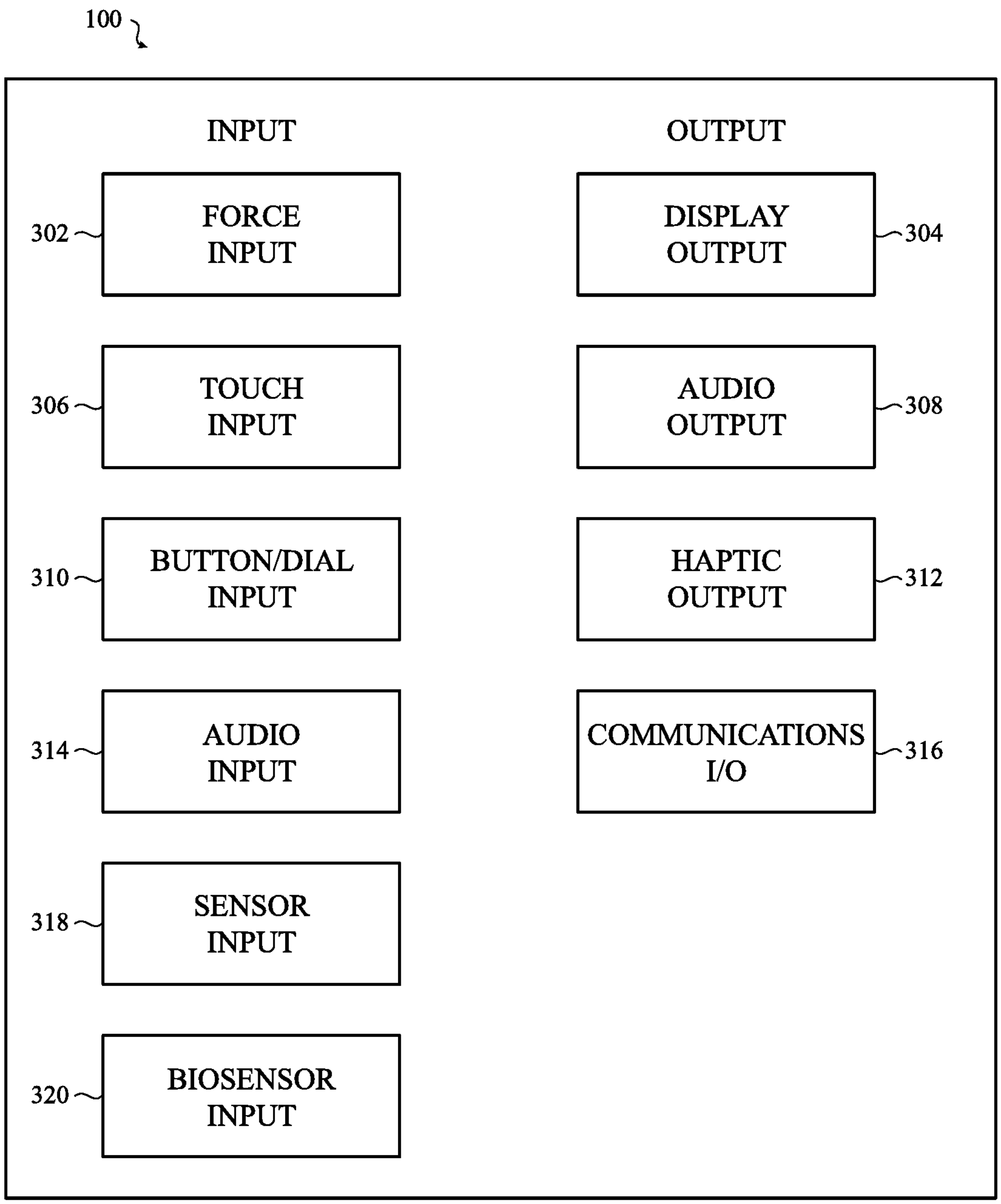
BATTERY
WIRELESS POWER
116
118
BIO SENSORS
DISPLAY
120
122
SPEAKER
MICROPHONE
124

FIG. 2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INPUT
OUTPUT
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FORCE INPUT
DISPLAY OUTPUT
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TOUCH INPUT
AUDIO OUTPUT
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310
BUTTON/DIAL INPUT
HAPTIC OUTPUT
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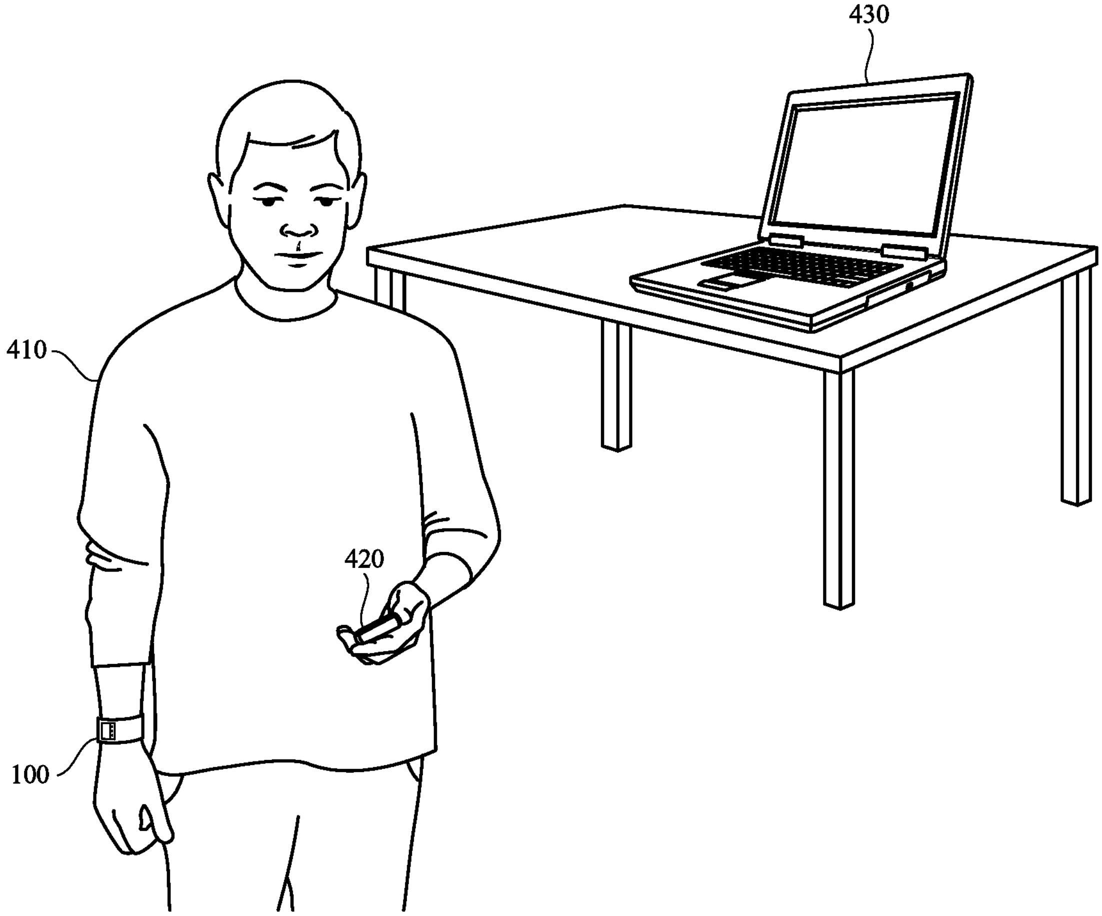
AUDIO INPUT
COMMUNICATIONS I/O
316
318
SENSOR INPUT
320
BIOSENSOR INPUT

FIG. 3



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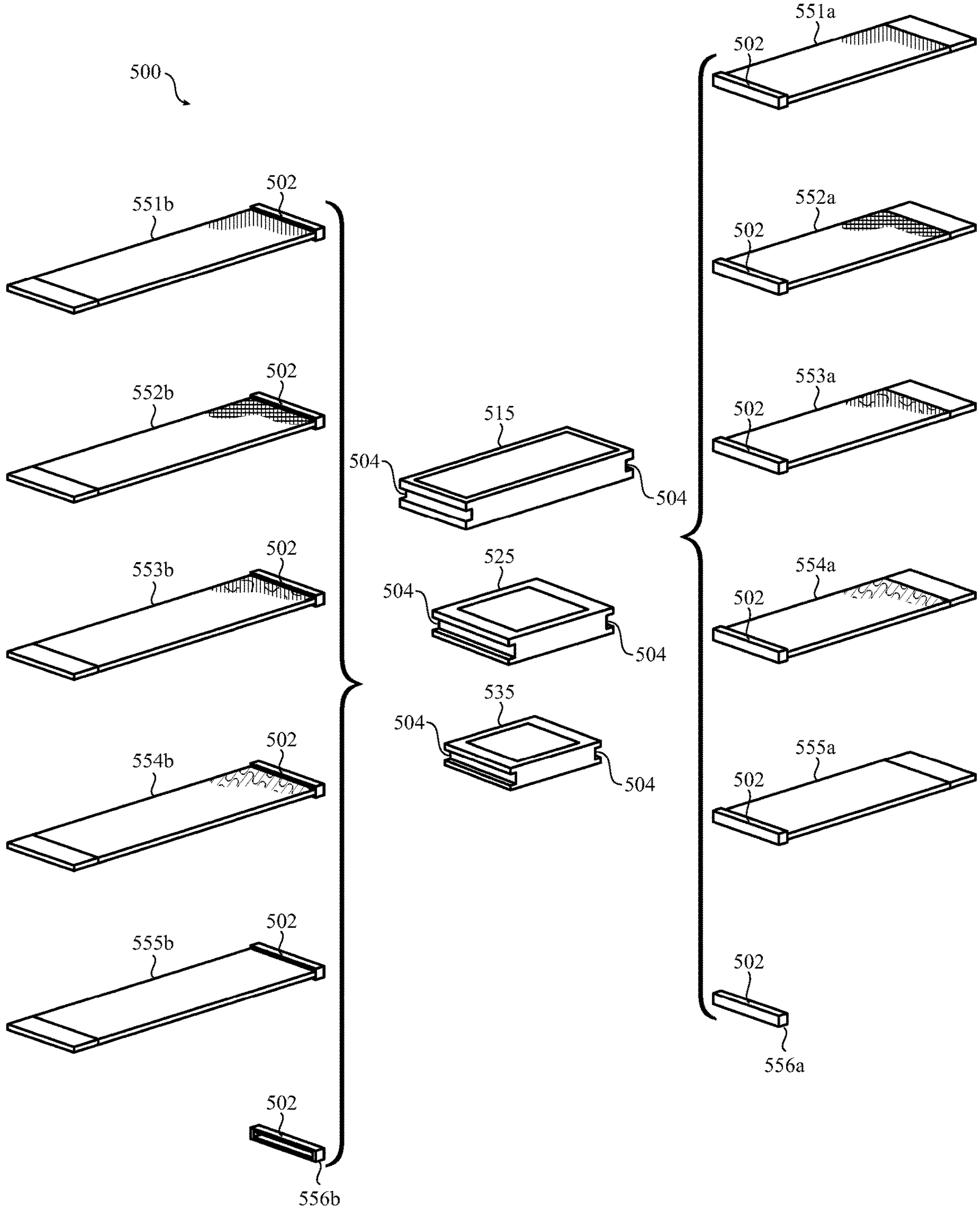
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FIG. 5

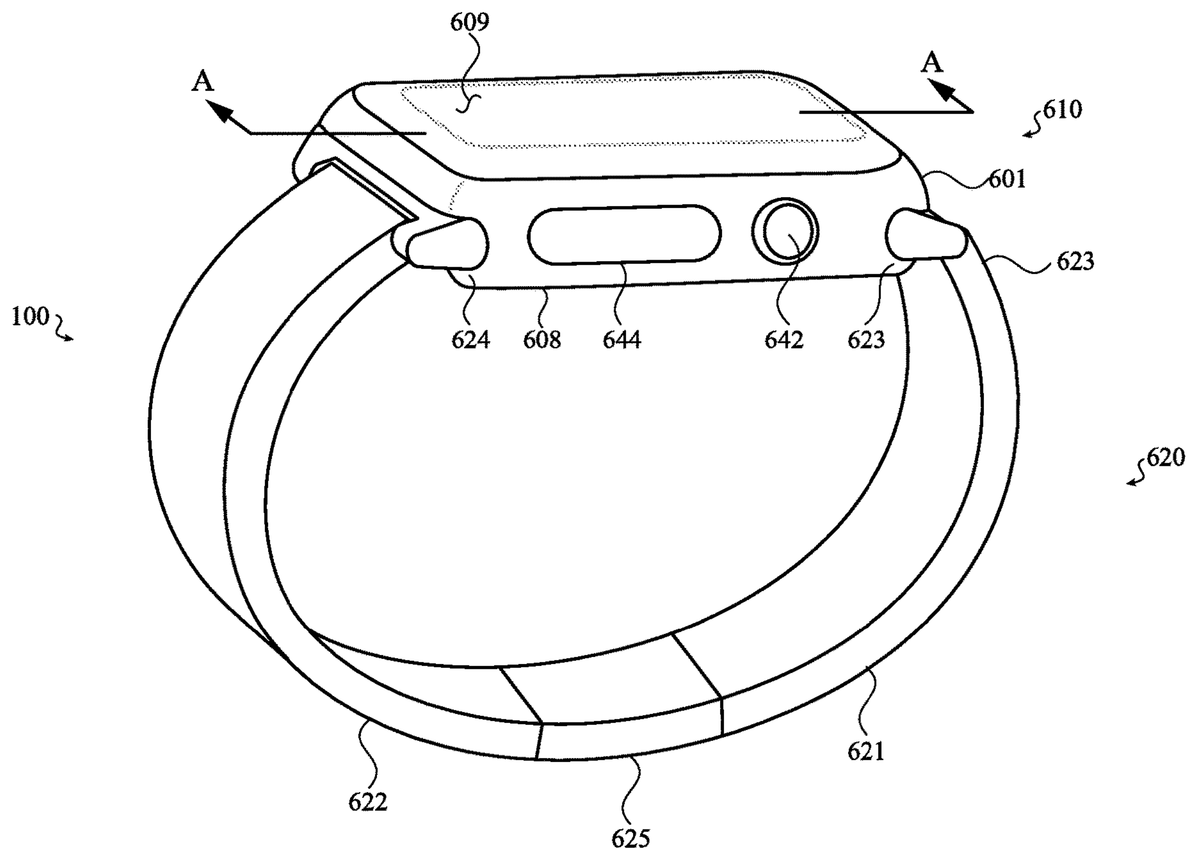

FIG. 6

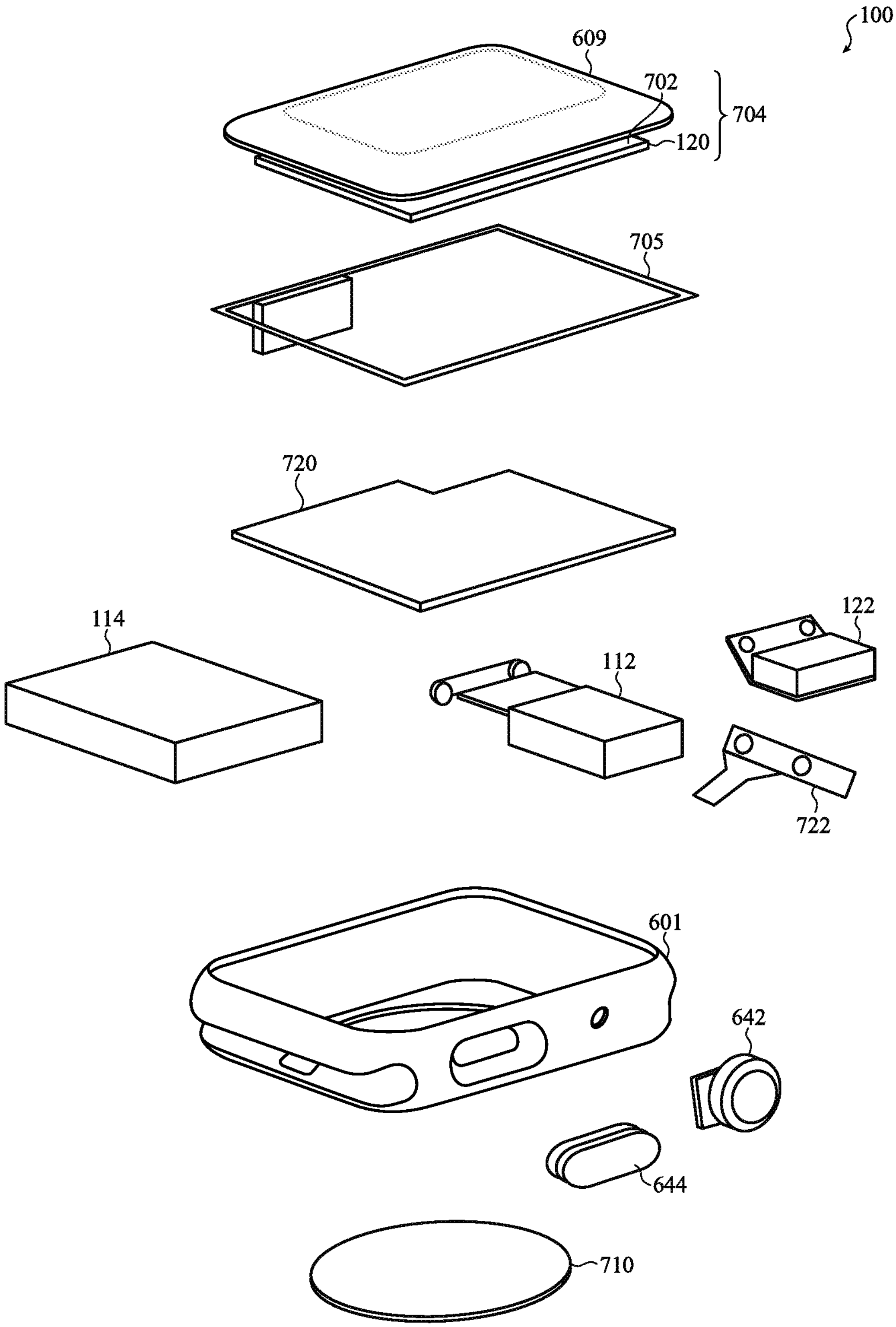

FIG. 7

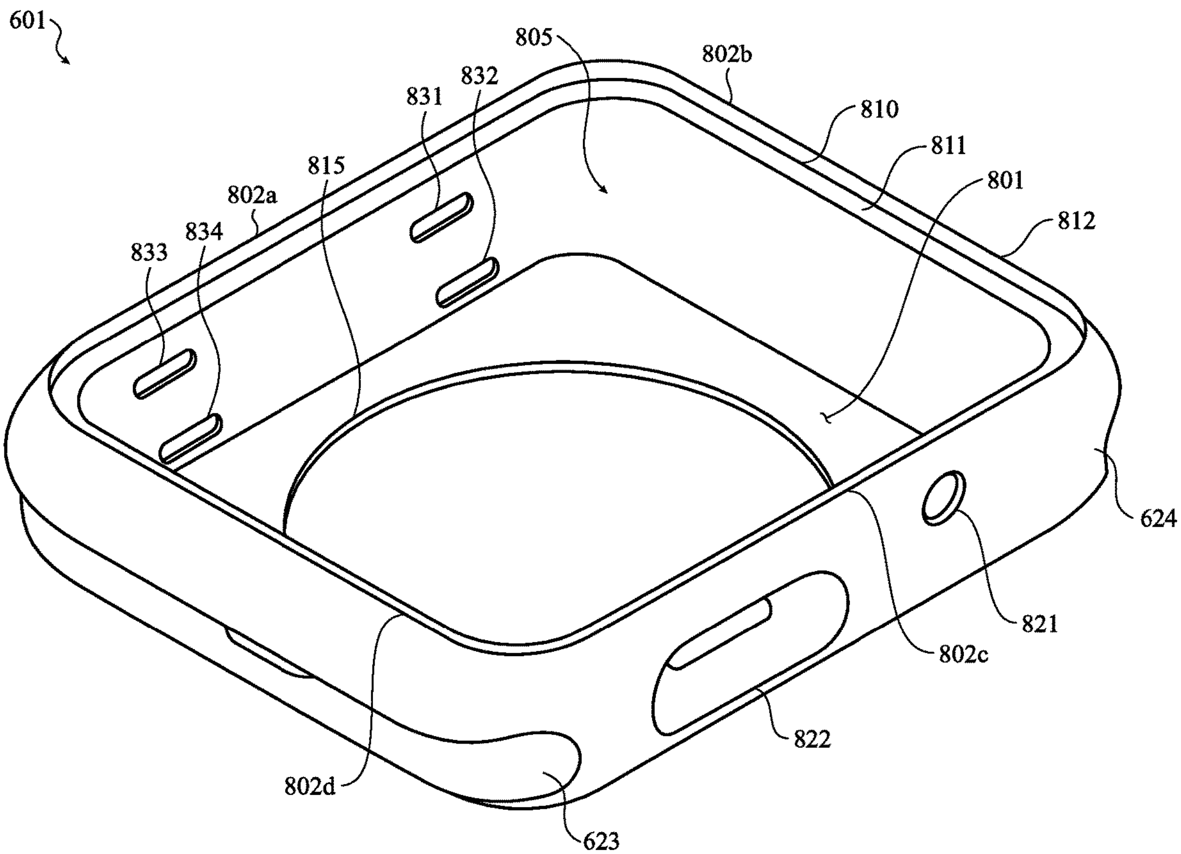
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FIG. 8

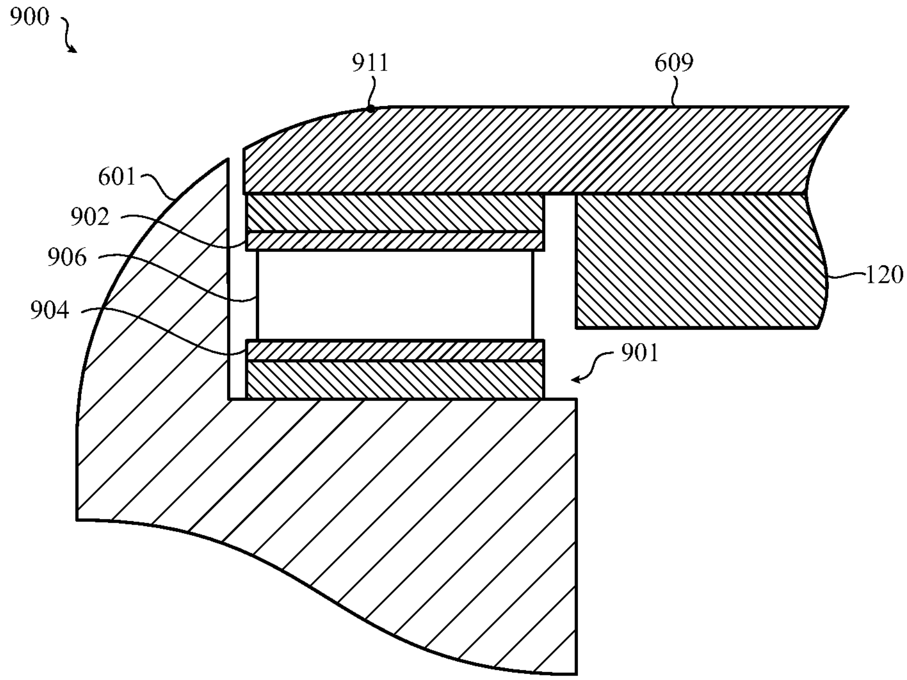

FIG. 9

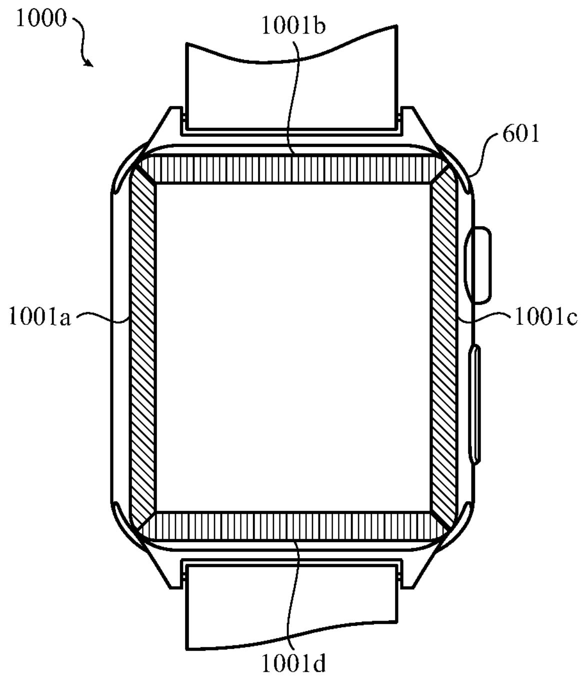

FIG. 10A

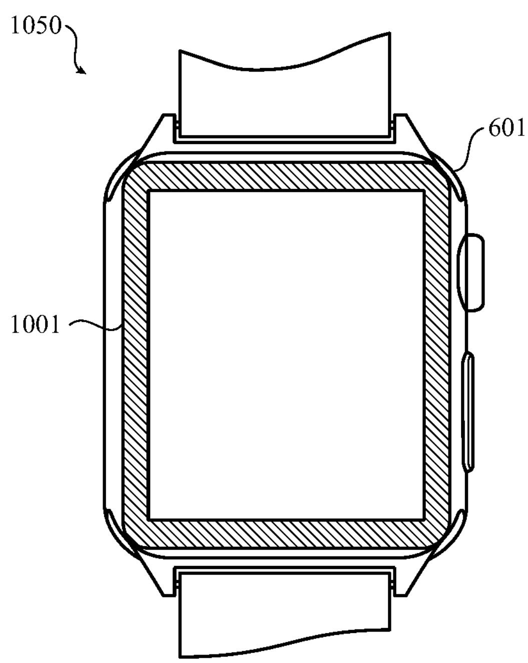

FIG. 10B

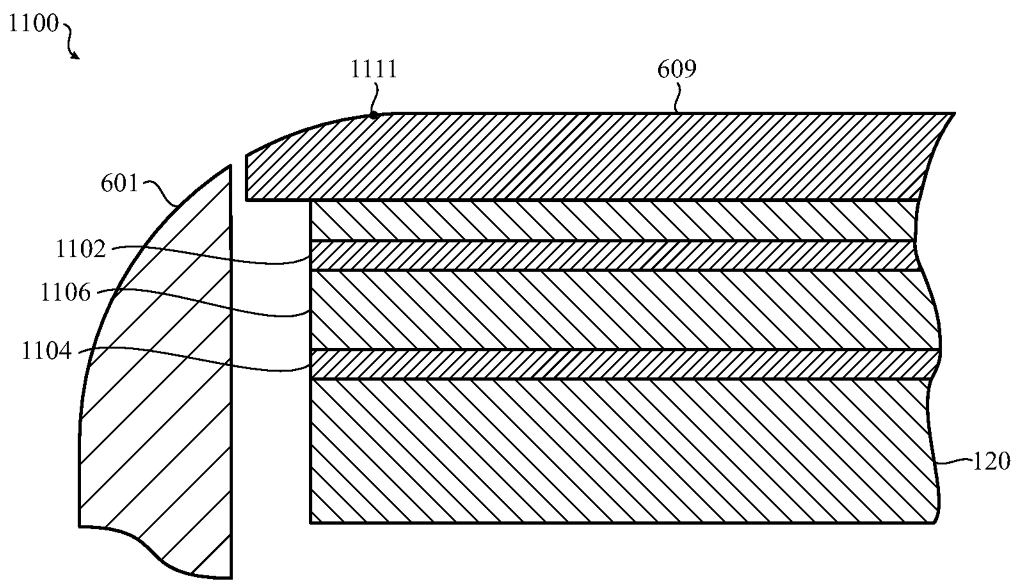

FIG. 11

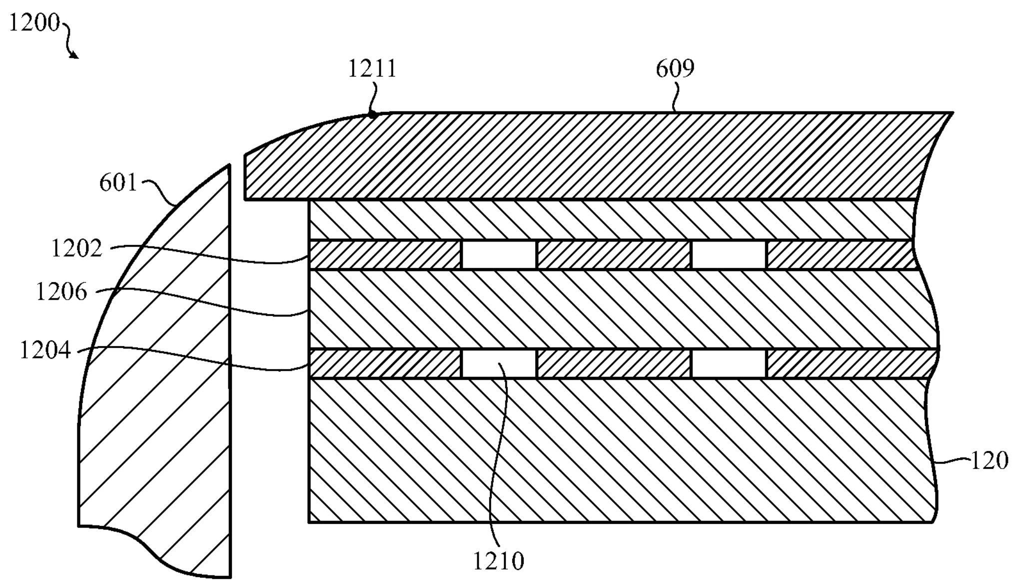

FIG. 12

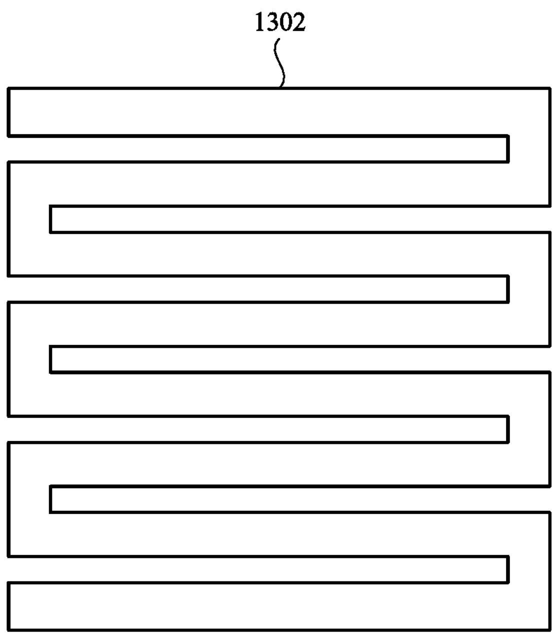

FIG. 13A

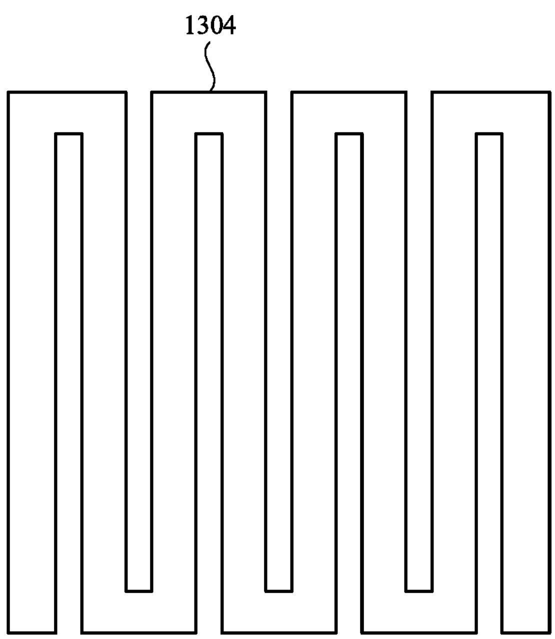

FIG. 13B

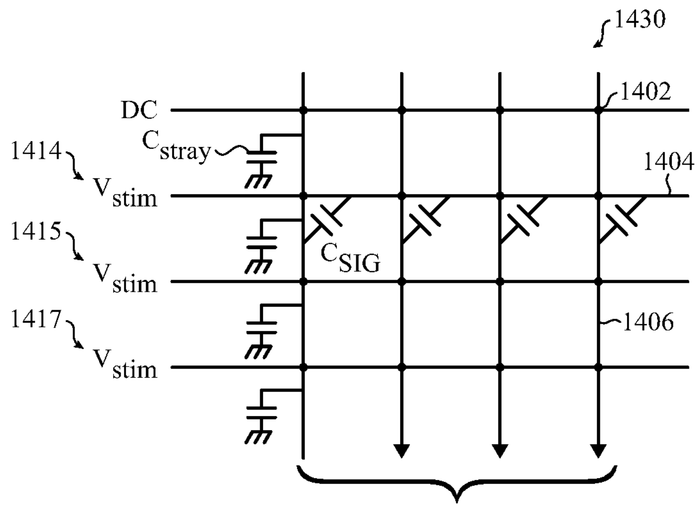

FIG. 14A

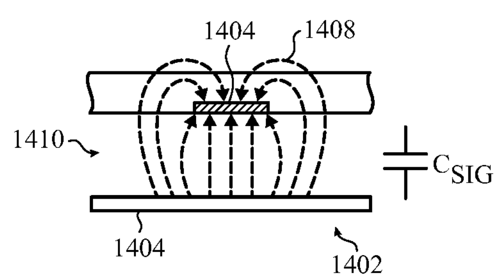

FIG. 14B

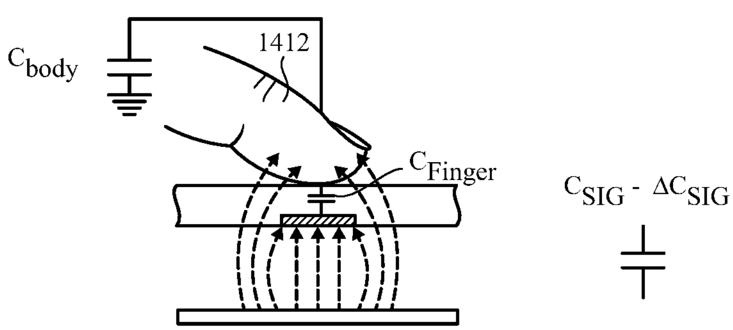

FIG. 14C

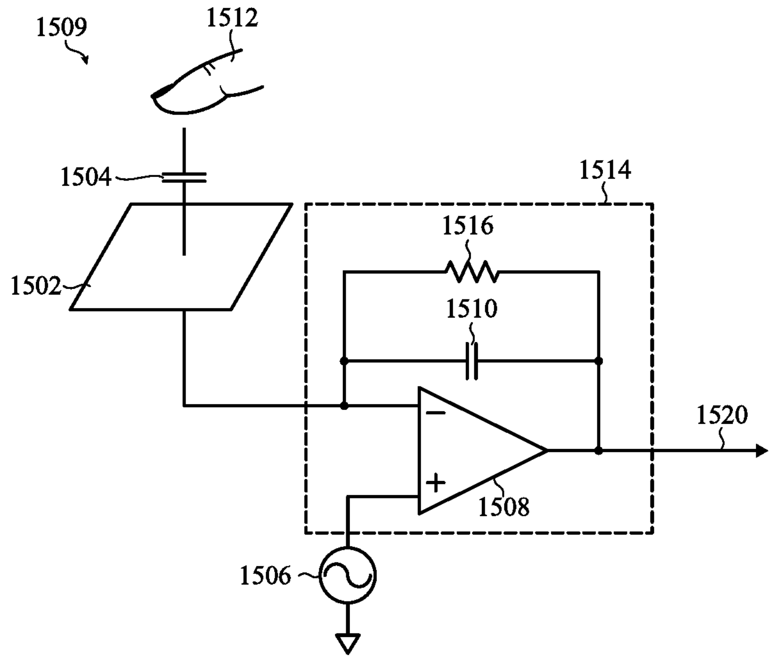

FIG. 15A

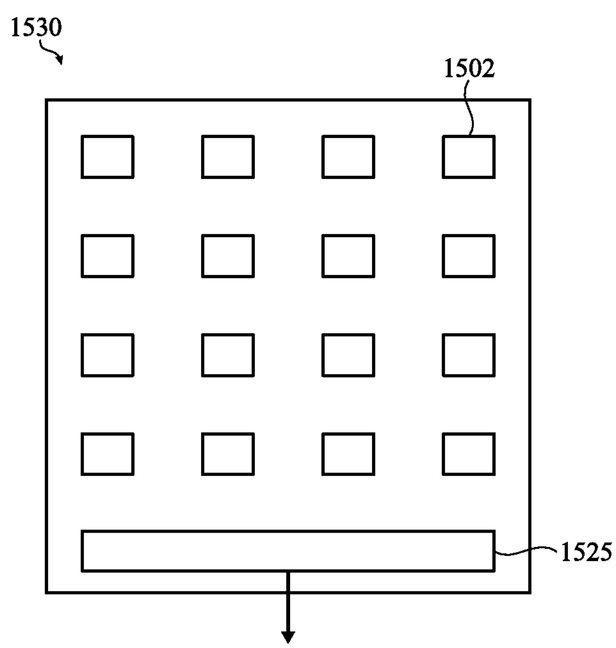

FIG. 15B

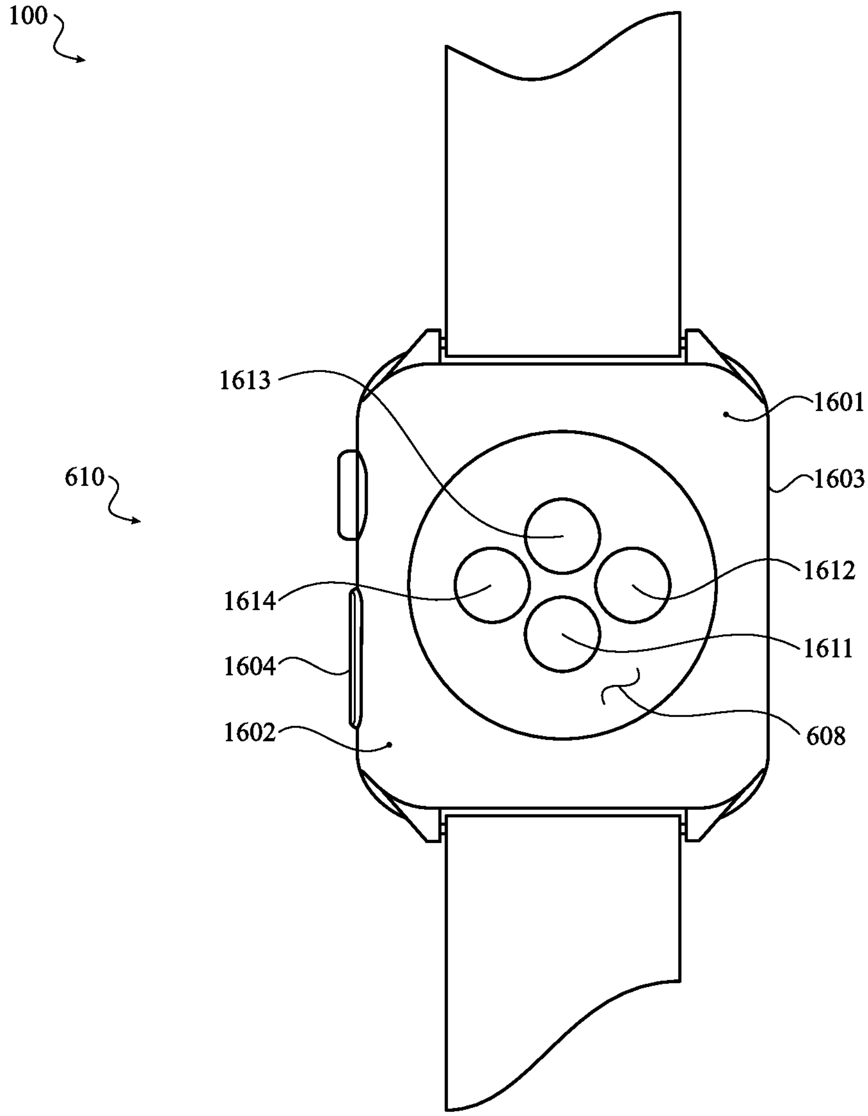

FIG. 16

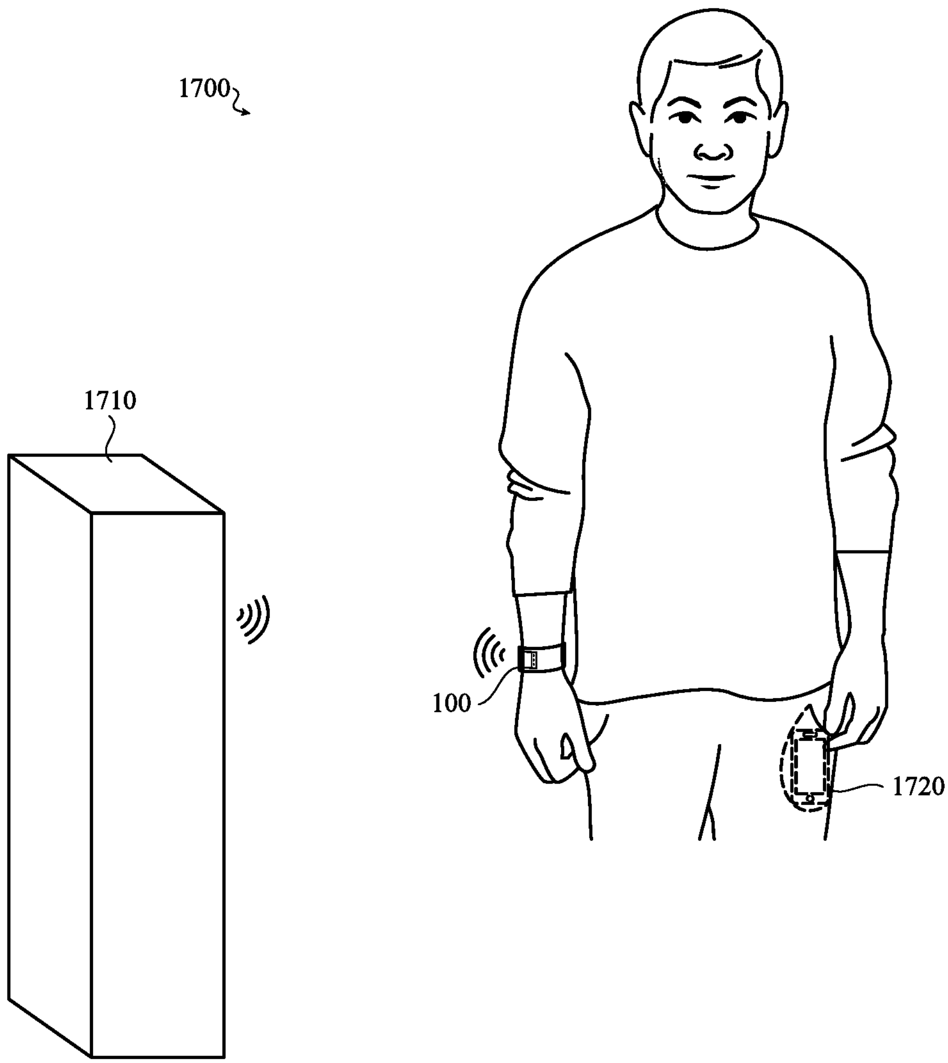

FIG. 17

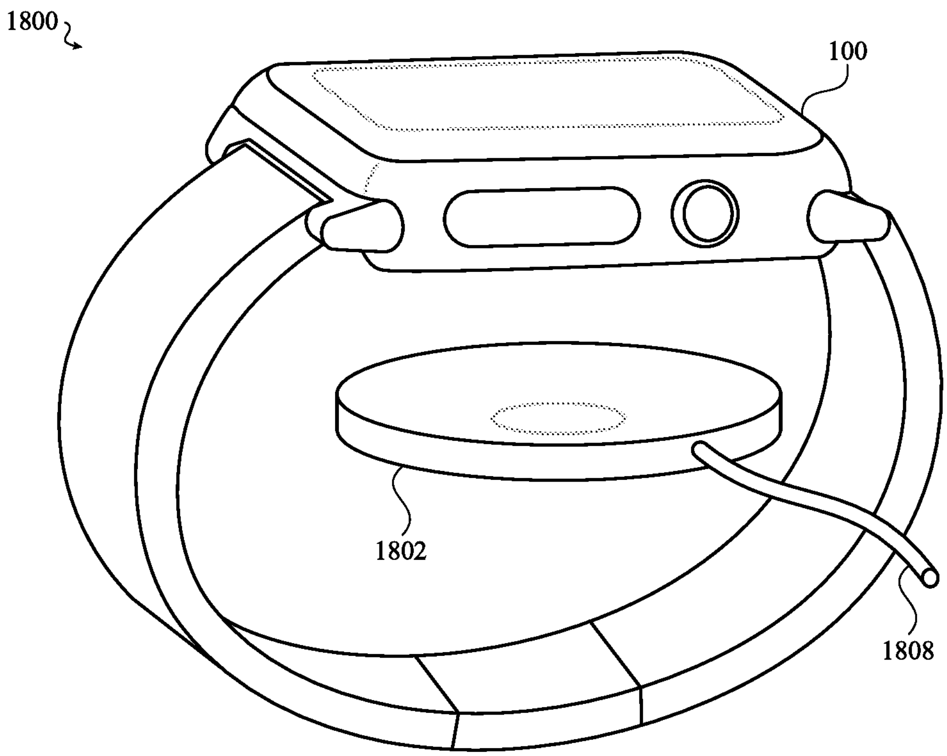

FIG. 18

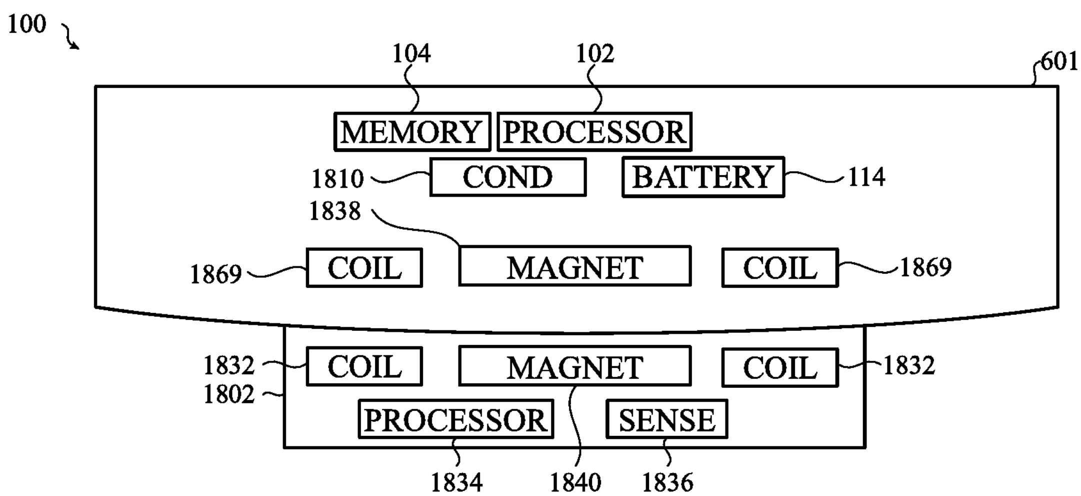

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FIG. 19

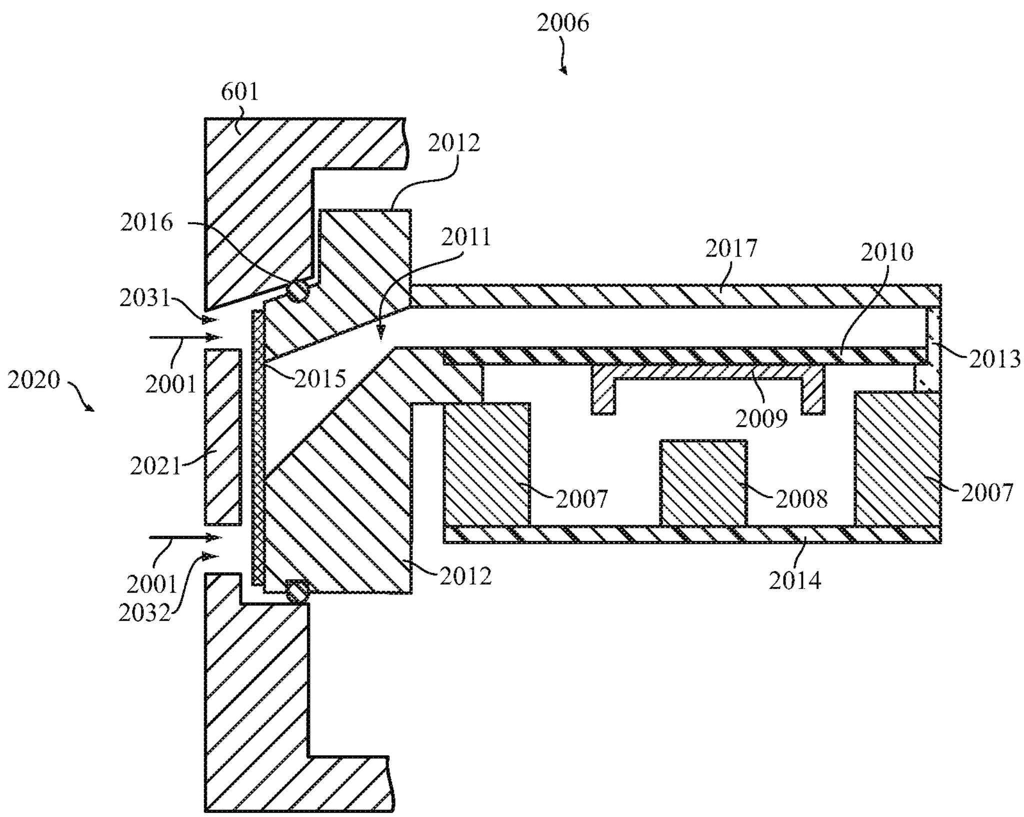
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FIG. 20

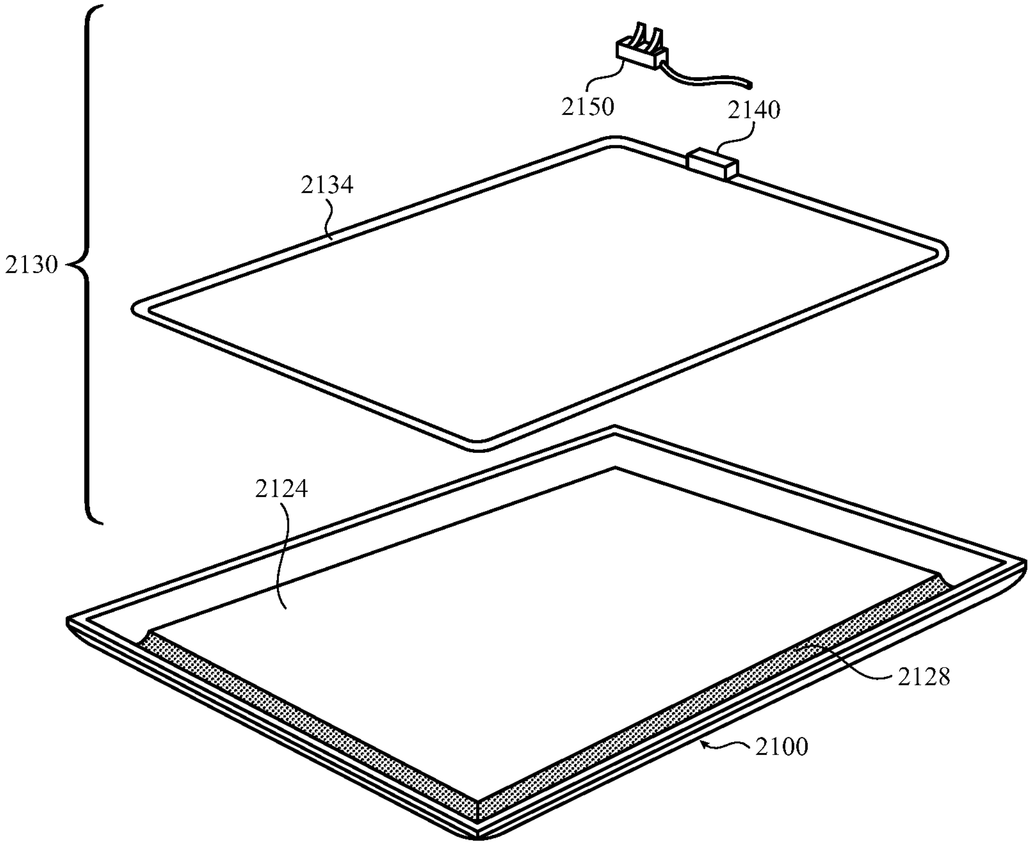

FIG. 21A

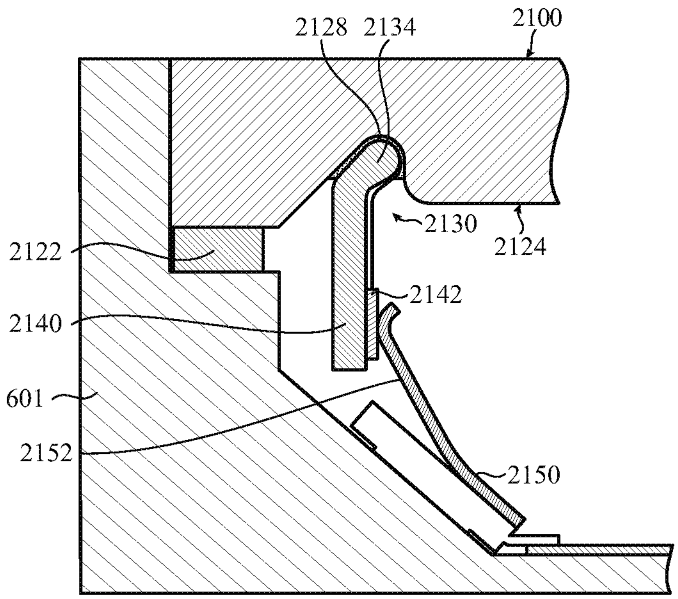

FIG. 21B

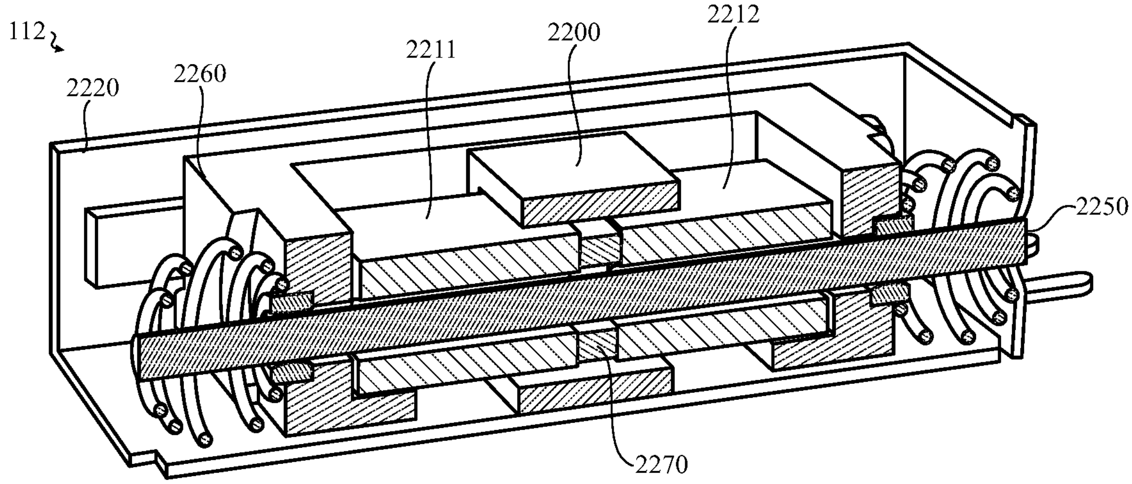

FIG. 22A

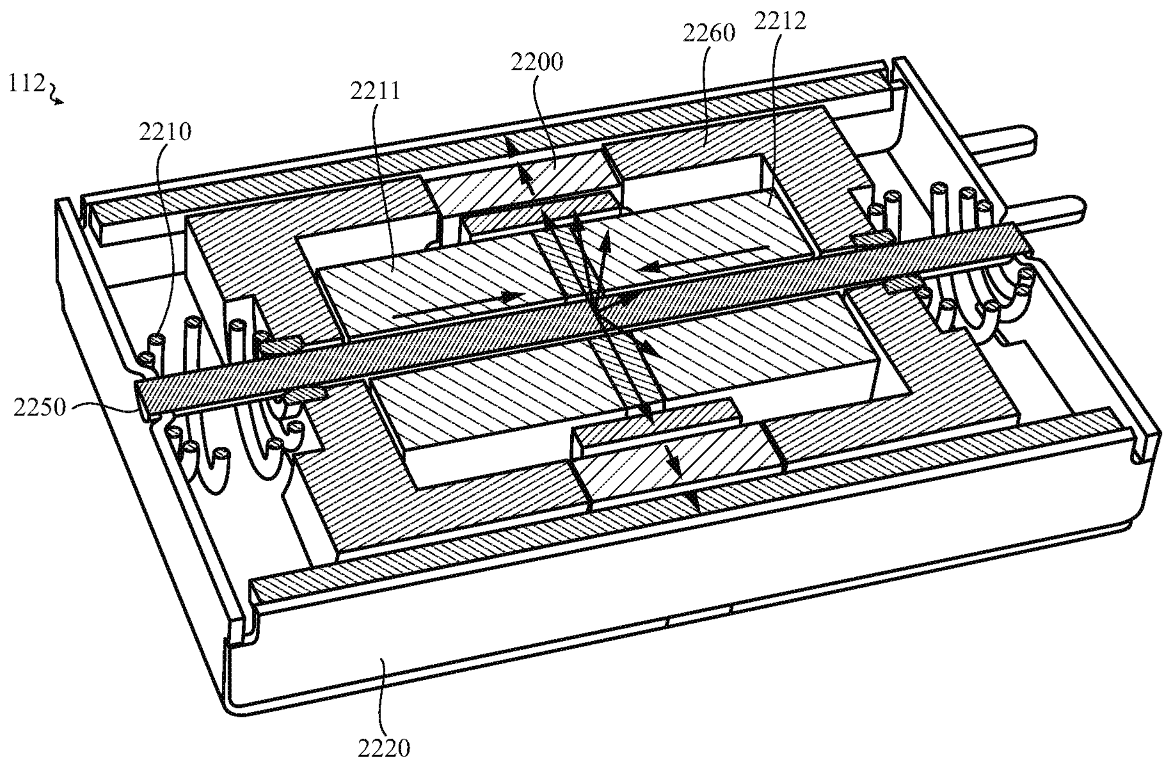

FIG. 22B

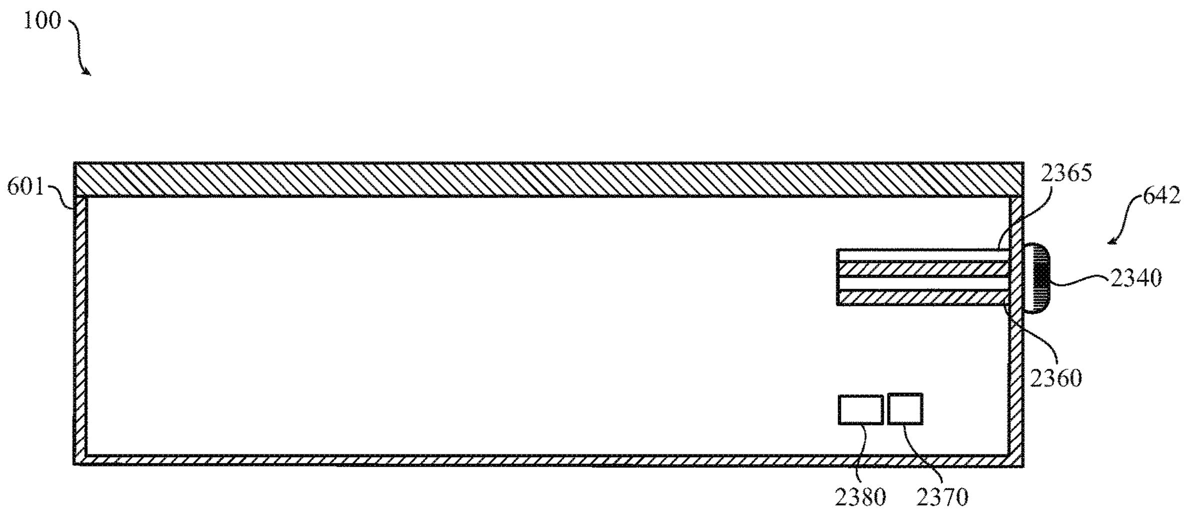

FIG. 23

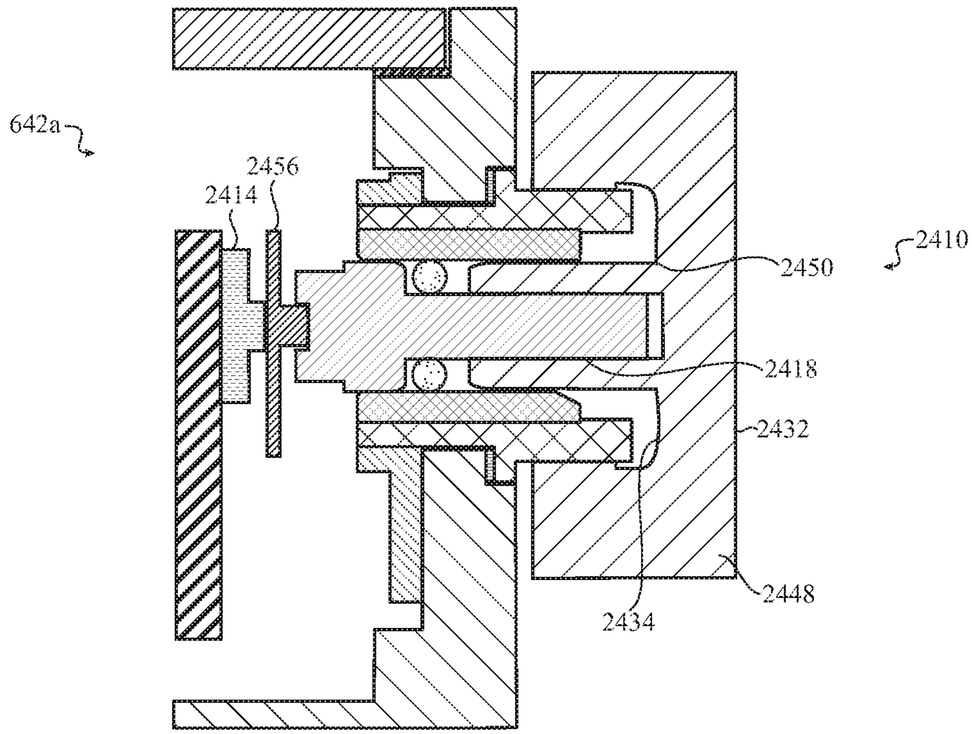

FIG. 24A

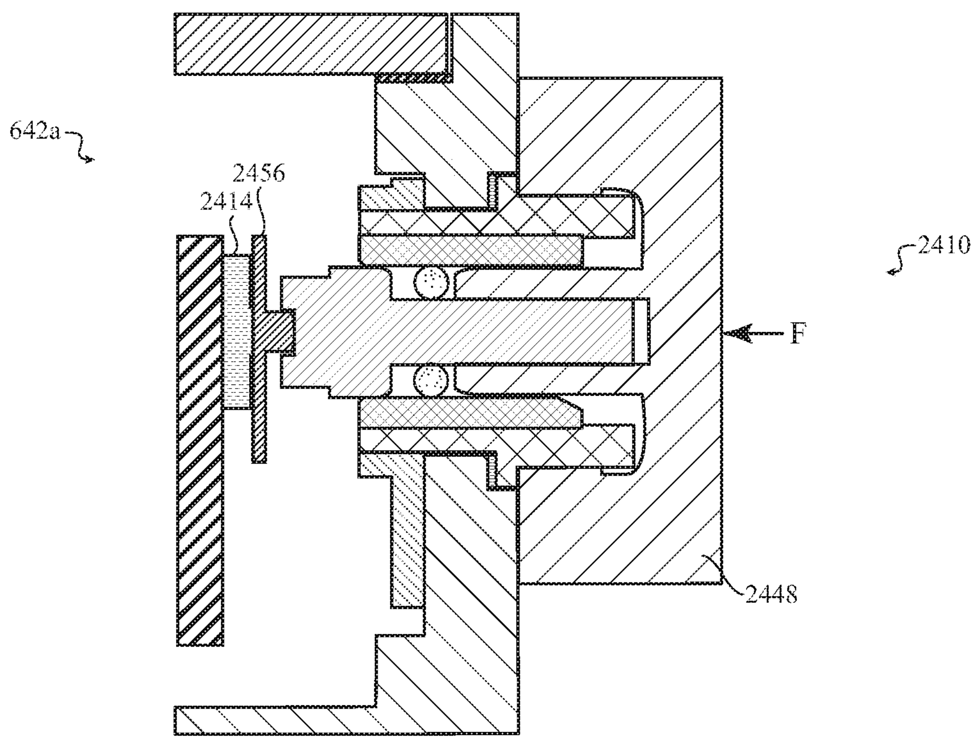

FIG. 24B

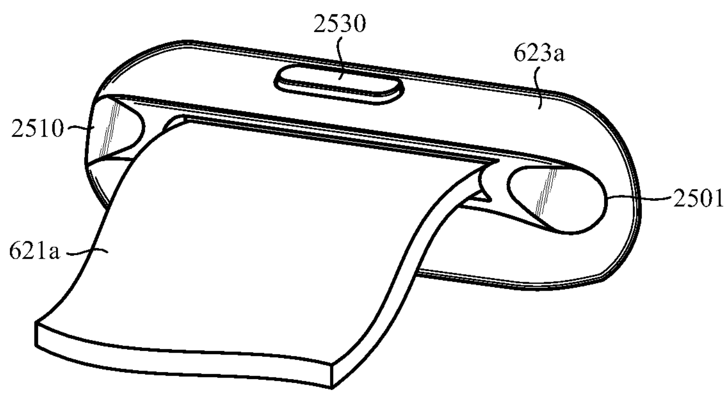

FIG. 25A

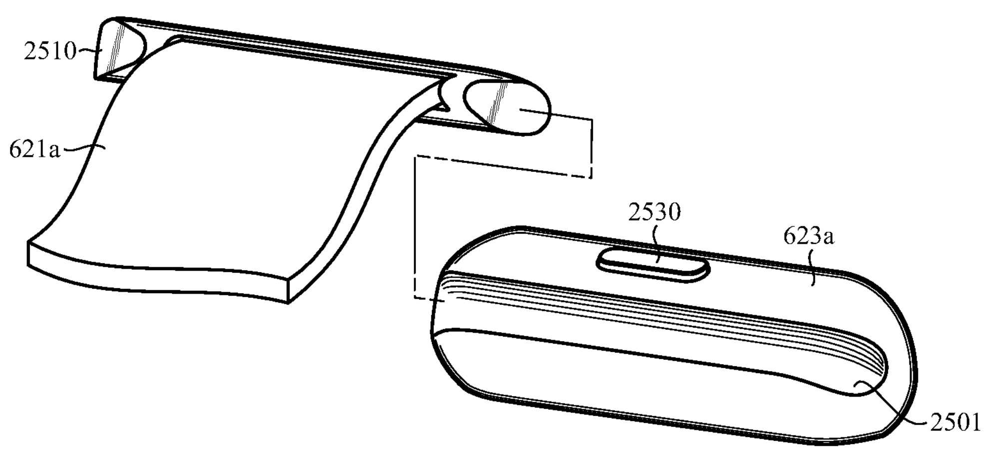

FIG. 25B

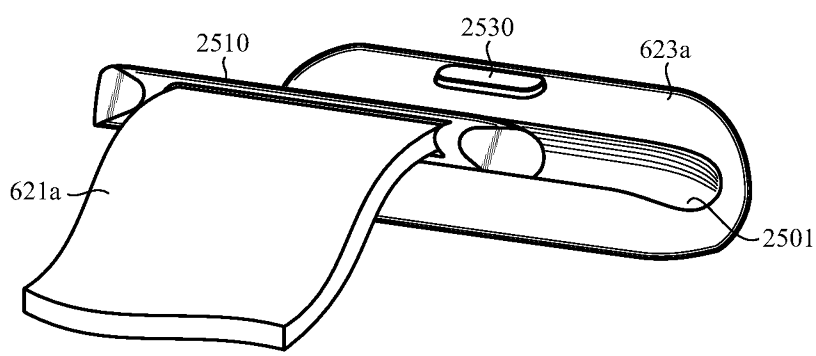

FIG. 25C

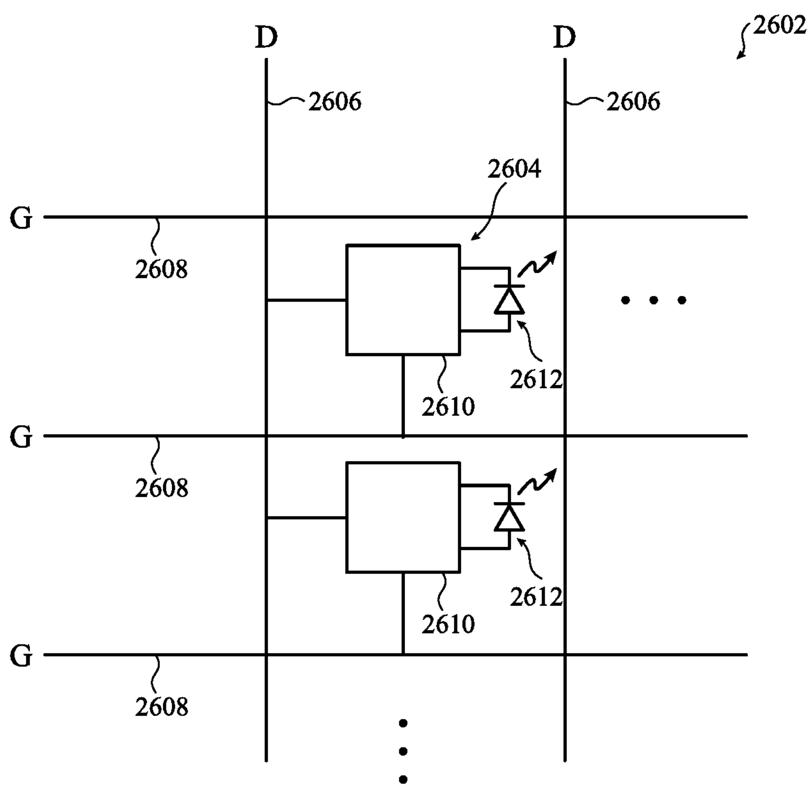

FIG. 26

WEARABLE ELECTRONIC DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation patent application of U.S. patent application Ser. No. 15/261,912, filed Sep. 10, 2016, and titled "Wearable Electronic Device," U.S. patent U.S. patent application Ser. No. 15/261,917, filed Sep. 10, 2016, and titled "Wearable Electronic Device," and U.S. patent application Ser. No. 14/842,617, filed Sep. 1, 2015, and titled "Wearable Electronic Device," which is a non-provisional patent application of and claims the benefit of U.S. Provisional Patent Application No. 62/044,974, filed Sep. 2, 2014, and titled "Wearable Electronic Device and Associated Methods of Use and Manufacture," the disclosures of which are hereby incorporated herein by reference in their entireties.

FIELD

The following disclosure generally relates to an electronic device, and more specifically to a wearable electronic device having a range of features, including touch input, force input, an interchangeable attachment system, health monitoring functionality, wireless power charging, wireless authentication and transaction functionality, and other features and functionality.

BACKGROUND

Portable electronic devices have become increasingly popular, and the features and functionality provided by portable electronic devices continue to expand to meet the needs and expectations of many consumers. However, some traditional portable electronic devices, particularly wearable electronic devices, may have relatively limited functionality or are only able to perform a specialized set of functions or tasks. For example, some traditional electronic wristwatches may be configured to perform a relatively limited set of functions, including displaying time, date, and performing basic timing functions. The embodiments described herein are directed to a wearable electronic device that provides a wide range of functionality, as compared to some traditional wearable electronic devices.

SUMMARY

The embodiments included herein are directed to a consumer product, which may include a portable or wearable electronic device that is configured to provide an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device.

Some example embodiments are directed to wearable electronic device having a housing that includes a flat bottom portion, a top portion defining a cavity, and a curved side portion that extends from the bottom portion to the top portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A display may be at least partially disposed within the cavity and may have a viewable area. The device may also include

a cover disposed above the display and including a flat middle portion larger than the viewable area of the display, a curved edge portion surrounding the flat middle portion and coinciding with the curved side portion along a perimeter of the cavity to form a continuous contoured surface.

In some embodiments, the continuous contoured surface is tangent with the flat bottom portion of the housing at a first end of the contour. The continuous contoured surface may also be tangent with the flat middle portion of the cover at a second end of the contour. In some embodiments, the continuous contoured surface has a constant radius.

In some embodiments, the cavity has a rectangular shape. The curved edge portion of the housing may have four sides that surround the cavity, each side is orthogonal to two adjacent sides. Each side may be connected to an adjacent side by a rounded corner. In some embodiments, the rounded corners have a curvature that corresponds to a curvature of the continuous contoured surface formed by the curved edge portion of the cover and the curved side portion of the housing.

Some embodiments include a crown module that is positioned at least partially within an aperture formed within the curved side portion of the housing. The crown module may include an outer surface configured to receive a rotary user input. The crown module may be offset with respect to a centerline of the housing between the top portion and the flat bottom portion. The offset may be toward the top portion of the housing. The crown module may include a dial having a portion that is higher than an interface between the cover and the housing.

In some example embodiments, a port is formed in the curved side portion of the housing. An acoustic module may be disposed within the housing and configured to produce an audio output through the port. The acoustic module may include an acoustic element and an acoustic cavity that acoustically couples the acoustic element to the port. The port may include an orifice that is offset with respect to the acoustic cavity to prevent the direct ingress of liquid into the acoustic module.

In some embodiments, the device includes a gasket positioned between the housing and the cover. The housing may also include a ledge formed along a perimeter of the cavity. The gasket may be positioned along the ledge that is formed along the perimeter of the cavity. The gasket, the cover, and the housing may be configured to cooperate to form a substantially water-proof seal.

In some example embodiments, the device includes a biosensor module that is disposed in an opening formed in the flat bottom portion of the housing. The biosensor module may include a chassis positioned in the opening of the housing and defining an array of windows. An array of light sources may be attached to the chassis and configured to emit light into the user through the array of windows. The biosensor module may also include an optically transparent rear cover disposed over the chassis and over the array of windows and operative to pass light emitted from the array of light sources into the user. In some embodiments, the rear cover has a convex outer contour.

Some example embodiments are directed to an electronic device having a housing comprising a bottom portion defining an opening and a band attached to the housing and configured to secure the electronic device to a user. A biosensor module may be disposed within the opening of the housing. A rear cover may be disposed over the biosensor module and may include an edge protruding outwardly from the bottom portion of the housing and an outer surface having a convex curved contour. In some embodiments, the

outer surface of the rear cover defines one or more windows that provide operational access to one or more optical components of the biosensor module. The one or more windows may have a curvature that matches the convex curved contour of the outer surface.

In some embodiments, the biosensor module includes an array of light sources that are configured to emit light into a body of the user. The biosensor module may also include a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. In some cases, the biosensor module is removably coupled to the housing.

In some embodiments, the device also includes a processing unit configured to compute a health metric associated with the user based on the sensor signal. The device may also include a display disposed within the housing and configured to display the health metric.

Some example embodiments are directed to a wearable electronic device, having a housing including a top portion, a cavity formed within the top portion, and a curved side portion that surrounds the cavity. The device may also include a transparent cover disposed over the cavity of the housing and may include a flat middle portion at a center of the transparent cover, a curved outer portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge of the transparent cover, and a mask positioned relative to an internal surface of the transparent cover. The mask may have an outer boundary located proximate to the edge of the transparent cover and an inner boundary located within the curved outer portion of the transparent cover.

In some embodiments, the device includes a display disposed below the transparent cover. A perimeter portion of a viewable area of the display may be disposed below the mask. The device may also include an antenna having a shape that corresponds to a shape of the cavity formed within the housing. The antenna may be disposed in a groove formed in the internal surface of the transparent cover. The groove may be formed between the outer boundary and the inner boundary of the mask. In some embodiments, the cover is formed from a sapphire material. The antenna may be configured to facilitate wireless communication between the wearable electronic device and an external device.

Some example embodiments are directed to an electronic device having a housing including a first end, a second end opposite the first end, a first side extending between the first and second ends, and a second side opposite to the first side and extending between the first and second ends. The first end may define a first groove extending between the first and second sides and may be configured to receive a first lug portion of a first band. The second end may define a second groove extending between the first and second sides and may be configured to receive a second lug portion of a second band. The first and second grooves may have an inwardly curved concave shape with an undercut feature that retains the first and second lug portions. In some embodiments, the first groove extends through a solid portion of the housing to form a continuous interior shape.

In some embodiments, the device includes a display at least partially disposed within a cavity of the housing. A cover may be disposed above the display and at least a portion of the first groove is disposed below the cover. The first and second grooves may be formed at an angle with respect to a centerline of the housing. The first and second grooves may be angled upward toward a top of the housing and inward toward the center of the housing. The first and second grooves may cross the centerline of the housing.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A crown may be disposed relative to the housing and configured to receive a rotational input. An encoder may be operatively coupled to the crown and configured to produce an encoder output that corresponds to the rotational input. A speaker module may be disposed within the housing and configured to produce an audio output that corresponds to the encoder output. A haptic device may be disposed within the housing and configured to produce a haptic output that corresponds to the encoder output. In some embodiments, the haptic output is synchronized with the audio output. The crown may be further configured to translate along an axis and actuate a tactile switch.

In some embodiments, the device also includes a display element within the housing. The device may be configured to display a list of items on the display element and scroll the list of items in response to the encoder output. The device may also be configured to synchronize the audio and haptic outputs with the scrolling of the list of items. In some embodiments, the crown is further configured to translate along an axis and actuate a tactile switch. The crown may be operative to select an item of the list of items when the tactile switch is actuated.

Some example embodiments are directed to a wearable electronic device having a housing that includes a bottom portion and an aperture formed in the bottom portion. A band may be attached to the housing and configured to secure the wearable electronic device to a user. A biosensor module may be disposed in the aperture of the housing. The biosensor module may include an array of light sources configured to emit light into a body of the user, and a photodetector configured to receive light produced by a light source of the array of light sources that is reflected from the body and produce a sensor signal. The device may also include a processing unit that is configured to compute a health metric associated with the user based on the sensor signal. A display may be disposed within the housing and configured to display the health metric.

In some embodiments, the array of light sources and the photodetector are configured to function as multiple photoplethysmography (PPG) sensors. Each PPG sensor may be configured to be used to compute a separate health metric. In some embodiments, a first light source of the array of light sources includes a green LED adapted to detect blood perfusion in the body. A second light source of the array of light sources may include an infrared LED adapted to detect water content of the body. The health metric may include one or more of: a heart rate, a respiration rate, a blood oxygenation level, and a blood volume estimate.

In some embodiments, the device also includes at least one pair of electrodes disposed on an exterior surface of the housing. The at least one pair of electrodes may be configured to produce a signal when the at least one pair of electrodes is in contact with the body. In some case, the signal is used to compute an additional health metric that includes one or more of: a heart function, a body fat estimate, and a body fat estimate.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. The device may also include an array of light emitting diodes (LEDs) disposed within the housing, the array of LEDs being configured to emit light. A photodetector may be disposed within the housing and configured

to receive light produced by an LED of the array of LEDs that is reflected from a body of the user and produce a first sensor signal in response to the received light. The device may also include at least one pair of electrodes disposed on an exterior surface of the wearable electronic device. The electrodes may be configured to produce a second sensor signal when the electrodes are in contact with a respective portion of the body. The device may also include a processing unit that is configured to compute one or more health metrics based on the first and second sensor signals. The device may also include a display disposed at least partially within the housing and configured to display the one or more health metrics.

Some example embodiments are directed to a wearable electronic device including a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be disposed relative to the housing and a display may be attached to a lower surface of the cover. A force sensor may be positioned between the cover and the housing and attaching the cover to the housing. The force sensor may be configured to detect the force of a touch on the cover. The force sensor may also form a barrier to prevent ingress of liquid into the wearable electronic device. In some embodiments, an antenna may be disposed relative to the cover and external from the housing. The antenna may be configured to facilitate wireless communication with an external device.

In some example embodiments, a wearable electronic device may include a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A display element may be positioned within the housing and a rechargeable battery may be disposed within the housing and operatively coupled to the display element. The device may also include a receive coil within the housing configured to inductively couple with an external transmit coil. A power conditioning circuit may be configured to recharge the rechargeable battery using power received by the receive coil. The power conditioning circuit may be configured to provide power to the display element. The device may also include a first alignment magnet positioned within the receive coil and configured to align the device with respect to a second alignment magnet positioned within the external transmit coil.

Some example embodiments are directed to a wearable electronic device that includes a housing and a band attached to the housing and configured to secure the wearable electronic device to a user. A cover may be positioned relative to the housing and a display may be disposed within the housing and below the cover. A force sensor may be disposed within the housing and configured to detect a force of a touch on the cover. A touch sensor may be disposed between the display and the cover. The touch sensor may be configured to detect a location of the touch on the cover. In some embodiments, the force sensor is disposed along a perimeter of the display. The device may also include a processing unit and memory disposed within the housing. The processing unit may be configured to interpret a touch gesture on a surface of the cover using a force output from the force sensor and a touch output from the touch sensor.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements.

FIG. **1** depicts an example wearable electronic device having a device body and band.

FIG. **2** depicts an example schematic diagram of a wearable electronic device.

FIG. **3** depicts an example functional diagram for a wearable electronic device.

FIG. **4** depicts an example wearable electronic device as part of a system of devices.

FIG. **5** depicts a system of interchangeable components for a wearable device.

FIG. **6** depicts an example wearable electronic device having a device body and band.

FIG. **7** depicts an exploded view of components of an example wearable electronic device.

FIG. **8** depicts an example housing for a wearable electronic device.

FIG. **9** depicts an example force sensor configured to use a capacitive measurement.

FIGS. **10**A-B depict plan views of example force sensors.

FIG. **11** depicts an example force sensor configured to use a resistive measurement.

FIG. **12** depicts an example pixelated force sensor configured to use a resistive measurement.

FIGS. **13**A-B depict example force sensor structures.

FIGS. **14**A-C depict an example touch sensor based on mutual capacitance.

FIGS. **15**A-B depict an example touch sensor based on self capacitance.

FIG. **16** depicts an example device having biosensors.

FIG. **17** depicts an example device having wireless communications with an external device.

FIG. **18** depicts an example electronic device and example dock of an inductive charging system.

FIG. **19** depicts a block diagram of an example inductive charging system.

FIG. **20** depicts an example acoustic module.

FIGS. **21**A-B depict an example cover and antenna.

FIGS. **22**A-B depict an example haptic module.

FIG. **23** depicts an example device having a crown module with an encoder.

FIGS. **24**A-B depict an example device having a crown module with a tactile switch.

FIGS. **25**A-C depict an example receiving feature for a band.

FIG. **26** depicts example elements of a display.

DETAILED DESCRIPTION

Provided herein are descriptions and examples of a consumer product, which may include a portable electronic device, a wearable electronic device, or other type of device. By way of example and not by way of limitation, the consumer product may be an electronic device, a mechanical device, or an electromechanical device. Specific example devices include mobile phones, personal digital assistants, music players, timekeeping devices, health monitoring devices, tablet computers, laptop computers, glasses (electronic or otherwise), portable storage devices, and the like.

In one particular embodiment, the consumer product is a portable and, more specifically, a wearable consumer product. A wearable consumer product is one that can be worn by or otherwise secured to a user. For example, the consumer product may be a wearable electronic device including, but not limited to, a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and the like. A wearable consumer product may be worn by a user in a variety of

ways. In some examples, the consumer product is a wrist-worn product and may include a band that can be wrapped around a user's wrist to secure the consumer product to the user's body. The device may include one or more other types of attachments including, for example, an armband, lanyard, waistband, chest strap, and the like.

Some aspects of the disclosure are directed to a wearable electronic device having improved functionality and/or versatility as compared to some traditional wearable devices. For example, some aspects of the disclosure are directed to a consumer product, such as a portable electronic device, having an expansive feature set integrated or incorporated into a compact form factor. In some aspects of the present disclosure, a consumer product may integrate or combine multiple subsystems into a single device to provide a wide range of functionality, including biometric sensing, touch-based user input, near-field communications, and other desirable features. In some aspects, multiple subsystems are integrated into the relatively compact space of a wrist-worn device. Some aspects of the following disclosure are directed to the integration of a variety of subsystems or modules to provide functionality that may not be possible using some traditional device platforms. In some cases, the configuration and/or functionality provided by the various subsystems may be configurable by the end user, the manufacturer, and/or a vendor of the device. Example subsystems or modules of a consumer product and their respective functions are described below with respect to FIGS. **2** and **3**.

Some aspects of the disclosure are directed to a consumer product that is configured to communicate wirelessly with any of a number of other devices, such as a mobile phone, computer, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Through wireless communication with other devices, the consumer product may transmit and/or receive various notifications, messages, or other information between devices. The wireless communication may also facilitate the relay of alerts or other device outputs to notify the user of an event or action. In some aspects, the consumer product may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. An example communication system is described below with respect to FIG. **4** and with respect to other examples provided herein.

In some aspects, the consumer product may include a system of interchangeable components used to attach or secure the consumer product to the user. The system of interchangeable components may include a set of interchangeable bands or attachment devices that are configured to connect or attach to a receiving feature on the body of the product. The receiving feature may be standardized within the system of interchangeable components and allow multiple types of bands or attachment devices to be used with the same housing or body. The system of interchangeable components may also allow for an interchange between different bodies, which may include different types of electronic devices or other consumer products. Each body of the different devices or products may have a similar receiving feature that is standardized within the system of interchangeable components. An example system of interchangeable components is described below with respect to FIG. **5** and with respect to other examples provided herein.

Some aspects of the present disclosure are directed to a consumer product that includes a body that includes a case or housing used to protect as well as support the internal components of the product in their assembled position. The housing may enclose and support various components, including, for example, integrated circuits, subsystems, modules, and other internal components of the device. In some aspects, the housing forms a water-resistant or waterproof barrier and also provides structural rigidity necessary to protect internal components. The housing may be formed as a single piece, which may enhance the structural rigidity, water impermeability, and manufacturability of the housing. An example housing and example internal components for a consumer product are provided below with respect to FIGS. **6-8** and with respect to other examples provided herein.

In some aspects, the consumer product includes a force sensor that is configured to detect and measure the magnitude of a force or pressure on a surface of the product. In some implementations, the force sensor includes a capacitive-based sensor that is configured to estimate the force based on a deflection or movement between capacitive plates that is caused by and correlates to the amount of force caused by a touch. In some implementations, the force sensor is a resistance- or charge-based sensor that is configured to estimate the force based on the deflection of a sheet or film that is positioned relative to the touch-sensitive surface of the product. In some implementations, the output from the force sensor is combined with the output from a touch sensor, which may be self-capacitive or mutually capacitive, or a combination of the two. Example force and touch sensors are described below with respect to FIGS. **9-15**B and with respect to other examples provided herein.

In some aspects, the consumer product includes one or more biosensors. The biosensors may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. Example health metrics include, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. In some embodiments, the biosensors include an electrical sensor that may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. An example consumer product having multiple biosensors is described below with respect to FIG. **16** and with respect to other examples herein.

In some aspects, the consumer product is configured to perform wireless communication with an external device. In some implementations, the wireless communication may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce. An example consumer product having wireless communications with an external device is described in more detail below with respect to FIG. **17** and with respect to other examples herein.

In some aspects, the consumer product is configured to recharge an internal battery using a wireless charging system. In some implementations, the consumer product includes one or more receiving inductive coils that are configured to cooperate with one or more transmitting inductive coils that are located in a charging dock or other external device. The wireless charging system may allow the transfer of power and/or wireless communications with the consumer product without the use of an external port or terminal connection. An example consumer product having wireless charging capabilities is described in more detail below with respect to FIGS. **18-19** and with respect to other examples herein.

In some aspects, the consumer product includes one or more acoustic modules that are configured to function as a speaker and/or a microphone for the product. The speaker and/or microphone may include features that enhance the water/liquid resistance or impermeability of the consumer product. The consumer product may also include a haptic module or actuator that is configured to produce a haptic output that may be perceived by the user. In some implementations, the output of an acoustic module, such as a speaker, and the haptic module may be used to provide feedback or an alert to the user. In some cases, an acoustic module and the haptic module provide feedback to the user and may be coordinated with a user input, such as user-interface selecting, user-interface scrolling, or other user input command. An example acoustic module is described below with respect to FIG. **20** and an example haptic module is described below with respect to FIGS. **22**A-B.

In some aspects, the consumer product includes a dial or crown that is coupled to an encoder or other rotary sensor for detecting a rotary input. In some implementations, the output from the optical encoder is used to drive an aspect of a user interface or control other functionality of the product. Additionally, the dial or crown may include a tactile switch that can be actuated by pressing inward on the dial or crown. An example consumer product having a crown is described below with respect to FIGS. **23**-**24**B and with respect to other examples herein.

The description that follows includes sample devices, components, modules, systems, methods, and apparatuses that embody various elements of the present disclosure. However, it should be understood that various elements of the described disclosure may be combined and/or practiced in a variety of forms in addition to those described herein. In particular, the modules and components are described in a particular combination with respect to some examples provided below. However other combinations are possible, which may be achieved by adding, removing, and/or re-arranging modules to obtain a device or system having the desired characteristics.

FIG. **1** depicts a wearable consumer product **10**. For example, the consumer product **10** may be a wearable electronic device. In one example, the consumer product **10** may be a wearable multifunctional electronic device including multiple functionalities such as time keeping, health monitoring, sports monitoring, medical monitoring, communications, navigation, computing operations, and/or the like. The functionalities may include but are not limited to: keeping time; monitoring a user's physiological signals and providing health-related information based on those signals; communicating (in a wired or wireless fashion) with other electronic devices or services, which may be different types of devices having different functionalities; providing alerts to a user, which may include audio, haptic, visual and/or other sensory output, any or all of which may be synchronized with one another; visually depicting data on a display; gathering data form one or more sensors that may be used to initiate, control, or modify operations of the device; determining a location of a touch on a surface of the device and/or an amount of force exerted on the device, and using either or both as input; accepting voice input to control one or more functions; accepting tactile input to control one or more functions; capturing and transmitting images; and so on. These and other functions and features will be described in more detail herein.

The wearable consumer product **10** can take a variety of forms. In one example, the consumer product **10** may be a wrist-worn electronic device. The device may include a variety of types of form factors including, wristbands, armbands, bracelets, jewelry, and/or the like.

In the illustrated embodiment, the consumer product **10** includes a device body **11**. The device body **11** may include a housing that carries, encloses and supports both externally and internally various components (including, for example. integrated circuit chips and other circuitry) to provide computing and functional operations for the consumer product **10**. The components may be disposed on the outside of the housing, partially within the housing, through the housing, completely inside the housing, and the like. The housing may, for example, include a cavity for retaining components internally, holes or windows for providing access to internal components, and various features for attaching other components. The housing may also be configured to form a water-resistant or water-proof enclosure for the body **11**. For example, the housing may be formed from as a single unitary body and the openings in the unitary body may be configured to cooperate with other components to form a water-resistant or water-proof barrier.

Examples of components that may be contained in the device body **11** include processing units, memory, display, sensors, biosensors, speakers, microphones, haptic actuators, batteries, and so on. In some cases, the device body **11** may take on a small form factor. In cases such as these, the components may be packaged and/or in order to provide the most functionality in the smallest space. The components may also be configured to take up a minimal amount of space, which may facilitate the device body **11** having a small form factor. Additionally, the integration and assembly of the various components may be configured to enhance the reliability of the consumer product **10**.

The construction of the housing of the device body **11** may be widely varied. For example, housing may be formed from a variety of materials including plastic, rubber, wood, silicone, glass, ceramics, fiber composites, metal or metal alloys, (e.g., stainless steel, aluminum), precious metals (e.g., gold, silver), or other suitable materials, or a combination of these materials.

Also in the illustrated embodiment, the wearable electronic device includes a band **12** or strap or other means for attaching to a user. The band **12** may, for example, be configured to attach to the body and provide a loop for securing to the wrist of the user. The band **12** may be integral with the housing or it may be a separate part. If integral, the band **12** may be a continuation of the housing. In some cases, the integral band may be formed from the same material as the housing. If the band **12** is separate, the band may be fixed or releasably coupled to the housing. In both cases, the band **12** may be formed from similar or different materials as the housing. In most cases, the band **12** is formed from a flexible material such that it can conform to a user's body. Furthermore, the band **12** itself may be a single integral part or it may include attachment ends that provide an open and closed configuration. The attachment ends may, for example, be manifested as a clasp or other similar attachment mechanism or device. This particular configuration allows a user to open the band **12** for placement on the arm and close the band **12** in order to secure the band and body to the arm. The band **12** may be widely varied. By way of example, they may be formed from rubber, silicone, leather, metal, mesh, links and/or the like.

FIG. **2** depicts an example schematic diagram of a wearable electronic device. By way of example, device **100** of FIG. **2** may correspond to the consumer product **10** shown in FIG. **1**. To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incor-

porated into, or performed by device **100**, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device **100** may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein.

As shown in FIG. **2**, the device **100** includes one or more processing units **102** that are configured to access a memory **104** having instructions stored thereon. The instructions or computer programs may be configured to perform one or more of the operations or functions described with respect to the device **100**. For example, the instructions may be configured to control or coordinate the operation of a display **120**, one or more input/output components **106**, one or more communication channels **108**, one or more sensors **110**, a speaker **122**, a microphone **124** and/or one or more haptic feedback devices **112**.

The processing units **102** of FIG. **2** may be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processing units **102** may include one or more of: a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

The memory **104** can store electronic data that can be used by the device **100**. For example, a memory can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing and control signals or data for the various modules, data structures or databases, and so on. The memory **104** can be configured as any type of memory. By way of example only, the memory can be implemented as random access memory, read-only memory, Flash memory, removable memory, or other types of storage elements, or combinations of such devices.

In the schematic diagram of FIG. **2**, the one or more input components **106** are represented as a single item within the schematic diagram. However, input components **106** may represent a number of different input components, including buttons, switches, and dials for accepting user input, and so on. More specifically, the input components **106** may correspond to the buttons, dials, crowns or other devices for receiving input. Generally, the input components **106** are configured to translate a user-provided input into a signal or instructions that may be accessed using instructions executed on the processing units **102**. In the present example, the input components **106** may include the hardware configured to receive the user input (e.g., button, switch, crown, and encoder) which is operatively coupled to circuitry and firmware used to generate signals or data that are able to be accessed using processor instructions. Each input component **106** may include specialized circuitry for generating signals or data and, additionally or alternatively, circuitry and firmware for generating signals or data may be shared between multiple input components **106**. In some cases, the input components **106** produce user-provided feedback for application-specific input that corresponds to a prompt or user interface object presented on display **120**. For example, the crown (item **642** of FIG. **6**) may be used to receive rotational input from the user, which may be translated into an instruction to scroll a list or object presented on the display **120**. The input components **106** may also produce user input for system-level operations. For example the input components **106** may be configured to interact directly with hardware or firmware being executed on the device **100** for system-level operations, including, without limitation, power on, power off, sleep, awake, and do-not-disturb operations.

As shown in FIG. **2**, the device **100** may also include one or more acoustic elements, including a speaker **122** and a microphone **124**. The speaker **122** may include drive electronics or circuitry and may be configured to produce an audible sound or acoustic signal in response to a command or input. Similarly, the microphone **124** may also include drive electronics or circuitry and is configured to receive an audible sound or acoustic signal in response to a command or input. The speaker **122** and the microphone **124** may be acoustically coupled to respective ports or openings in the housing that allow acoustic energy to pass, but may prevent the ingress of liquid and other debris. As shown in FIG. **2**, the speaker **122** and microphone **124** are also operatively coupled to the processing units **102**, which may control the operation of the speaker **122** and microphone **124**. In some cases, the processing units **102** are configured to operate the speaker **122** to produce an acoustic output that corresponds to an application or system-level operation being performed on the device **100**. In some cases, the speaker **122** is operatively coupled to other modules, including, for example, input components **106**, such as a crown or button. In some implementations, the device **100** is configured to produce an audible output that corresponds to the operation of the crown or buttons using the speaker **122**. The microphone **124** may be configured to produce an output or signal in response to an acoustic stimulus. For example, the microphone **124** may be operatively coupled to the memory **104** and may be configured to record audio input, including human speech, music, or other sounds. In some cases, the microphone **124** may be configured to receive voice signals, which may be interpreted as voice commands by the processing units **102**.

The one or more communication channels **108** may include one or more wireless interface(s) that are adapted to provide communication between the processing unit(s) **102** and an external device. In general, the one or more communication channels **108** may be configured to transmit and receive data and/or signals that may be interpreted by instructions executed on the processing units **102**. In some cases, the external device is part of an external communication network that is configured to exchange data with wireless devices. Generally, the wireless interface may include, without limitation, radio frequency, optical, acoustic, and/or magnetic signals and may be configured to operate over a wireless interface or protocol. Example wireless interfaces include radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces.

In some implementations, the one or more communications channels **108** may include a dedicated wireless communication channel between the device **100** and another user device, such as a mobile phone, tablet, computer, or the like. In some cases, output, including audio sounds or visual display elements, are transmitted directly to the other user device for output to the user. For example, an audible alert or visual warning may be transmitted to a user's mobile phone for output on that device. Similarly, the one or more communications channels **108** may be configured to receive user input provided on another user device. In one example,

the user may control one or more operations on the device **100** using a user interface on an external mobile phone, table, computer, or the like.

Additionally, as described in more detail below with respect to FIG. **17**, the communications channels **108** may include a Near Field Communication (NFC) interface. The NFC interface may be used to identify the device and initiate a secure data connection, which may be used to authorize transactions, purchases, or conduct other forms of e-commerce.

As shown in FIG. **2**, the device **100** also includes one or more sensors **110** represented as a single item within the schematic diagram. However, the sensors **110** may represent a number of different sensors, including devices and components that are configured to detect environmental conditions and/or other aspects of the operating environment. Example sensors **110** include an ambient light sensor (ALS), proximity sensor, temperature sensor, barometric pressure sensor, moisture sensor, and the like. Thus, the sensors **110** may also be used to compute an ambient temperature, air pressure, and/or water ingress into the device. In some embodiments, the sensors **110** may include one or more motion sensors for detecting movement and acceleration of the device **100**. The one or more motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device.

The device **100** also includes one or more biosensors **118** and may include optical and/or electronic biometric sensors that may be used to compute one or more health metrics. As described in more detail below with respect to FIG. **16**, one or more of the biosensors **118** may include a light source and a photodetector to form a photoplethysmography (PPG) sensor. The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics including, without limitation, a heart rate, a respiration rate, blood oxygenation level, a blood volume estimate, blood pressure, or a combination thereof. One or more of the biosensors **118** may also be configured to perform an electrical measurement using one or more electrodes. The electrical sensor(s) may be used to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, one or more of the biosensors **118** may be configured to measure body temperature, exposure to UV radiation, and other health-related information.

The device **100** may also include one or more haptic devices **112**. The haptic device **112** may include one or more of a variety of haptic technologies such as, but not necessarily limited to, rotational haptic devices, linear actuators, piezoelectric devices, vibration elements, and so on. In general, the haptic device **112** may be configured to provide punctuated and distinct feedback to a user of the device. More particularly, the haptic device **112** may be adapted to produce a knock or tap sensation and/or a vibration sensation. As shown in FIG. **2**, the haptic device **112** may be operatively coupled to the processing unit **102** and memory **104**. In some embodiments, the haptic device **112** may be directly controlled by the processing unit **102**. In some embodiments, the haptic device **112** may be controlled, at least in part, by the operation of an input component **106**, including, for example, a button, dial, crown, or the like. The operation of the haptic device **112** may also be paired or linked to the operation of one or more other output devices, including, for example, the display **120** or the speaker **122**.

As shown in FIG. **2**, the device **100** may include a battery **114** that is used to store and provide power to the other components of the device **100**. The battery **114** may be a rechargeable power supply that is configured to provide power to the device **100** while it is being worn by the user. The device **100** may also be configured to recharge the battery **114** using a wireless charging system. Accordingly, in some cases, the device may include a wireless power module **116** that may be configured to receive power from an external device or dock. The wireless power module **116** may be configured to deliver power to components of the device, including the battery **114**. The wireless power module **116** and an external charging station or dock may also be configured to transmit data between the device and a base or host device. In some cases, the wireless power module **116** may interface with the wireless charging station or dock to provide an authentication routine that is able to identify specific hardware, firmware, or software on the device in order to facilitate device maintenance or product updates. A more detailed description of an example wireless charging station is provided below with respect to FIGS. **18-19**.

The device **100** may include a variety of other components, including for example, a camera or camera modules. The camera may be configured to capture an image of a scene or subject located within a field of view of the camera. The image may be stored in a digital file in accordance with any one of a number of digital formats. In some embodiments, the device **100** includes a camera, which includes an image sensor formed from a charge-coupled device (CCD) and/or a complementary metal-oxide-semiconductor (CMOS) device. The camera may also include one or more optical components disposed relative to the image sensor, including, for example, a lens, an filter, a shutter, and so on.

FIG. **3** depicts functional elements of the device **100**, in accordance with some embodiments. In particular, FIG. **3** depicts the inputs that may be received and outputs that may be produced on an example device **100**. By way of example, the device **100** may correspond to the devices shown in FIGS. **1** and **2**. As shown in FIG. **3**, the device **100** may include a force input **302** that may be produced using a force sensor that is configured to detect and measure the magnitude of a force of a touch on a surface of the device. The force input **302** may include a non-binary output that is generated in response to a touch. For example, the force input **302** may include a range of values or analog value that corresponds to the amount of force exerted on a surface of the device. Additionally or alternatively, the force input **302** may include binary (e.g., on, off) output in response to the force of a touch. The force input **302** may be used to control various aspects of the device. For example, the force input **302** may be used to control an aspect, such as a cursor or item selection on a user interface presented on the display of the device. The force input **302** may also be used to control the audio output **308**, haptic output **312**, and other functionality of the device. The force input **302** may also be used to distinguish between different types of input from the user. For example, a light touch from the user may be interpreted as a scroll command and used to index or scroll through a list of items on the display. A harder touch from the user may be interpreted as a selection or confirmation of an item on the display. In some embodiments, the force input **302** is used to distinguish an intentional touch from the user from an incidental or accidental touch that may be ignored.

As shown in FIG. **3**, the device **100** may also include a touch input **306** that may be produced using a touch sensor that is configured to detect and measure the location of a touch on a surface of the device. In some implementations, the touch sensor is a capacitive-based touch sensor that is disposed relative to the display or display stack of the device. The touch sensor may be a separate non-integrated

sensor relative to the force sensor. In alternative embodiments, the touch sensor may also be physically and/or logically integrated with the force sensor to produce a combined output. The touch input **306** may be used to control various aspects of the device. For example, the touch input **306** may be used to control an aspect of the user interface presented on the display of the device. The touch input **306** may also be used to control the audio output **308**, haptic output **312**, and other functionality of the device.

In some cases, the logical integration of the force input **302** and the touch input **306** enhances the versatility or adaptability of device **100** by enabling a more sophisticated user interface than is currently available on some traditional wearable devices. In particular, the force input **302** and the touch input **306** may be combined to interpret a wider range of gestures and input commands than may be possible using, for example, only a touch input. For example, the force input **302** may provide a magnitude of a force of a touch, which may be used to distinguish between two touch input commands that have a similar location or gesture path. An improved touch interface using both force input **302** and touch input **306** may be particularly advantageous when interpreting touch commands on a relatively small area surface, such as a display screen or cover glass of a wearable electronic device.

As shown in FIG. **3**, the device **100** may also include a button/dial input **310** that may be produced using an input device that is configured to receive input from the user. As described previously, the device **100** may include one or more buttons disposed on or near an external surface of the housing and are configured to receive input from a user. The device may also include a dial or crown that is configured to accept rotational input from the user. As described in more detail below with respect to FIGS. **24**A-B, the dial or crown may also include a push feature that is adapted to accept input from the user.

The device **100** may also accept audio input **314** using a microphone or other acoustic sensing device. The audio input **314** may be adapted to accept input from the user, including voice commands and other audio signal input. The audio input **314** may also be adapted to detect and measure ambient audio conditions that may be used to adjust the volume of the audio output **308** or operation of the haptic output **312**. The audio input **314** may also be used to record an audio stream or voice message in accordance with an audio recording application or software program.

As shown in FIG. **3**, the device **100** may include a display output **304** in accordance with some embodiments. The display output **304** includes visual or graphical output that may be produced using the display element of the device. In some embodiments, the display output **304** includes a graphical user interface produced using an operating system or software application executed on one or more processing units of the device. In one example, the display output **304** includes a graphical depiction that resembles a watch face or other timekeeping device. In other examples, the display output **304** includes a graphical interface for an e-mail, text messaging, or other communication-oriented program. The display output **304** may also present visual information that corresponds to one of the other functional aspects of the device **100**. For example, the display output **304** may include information that corresponds to the biosensor input **320**, sensor input **318**, force input **302**, touch input **306**, and others.

As shown in FIG. **3** the device **100** may include an audio output **308** that may be produced with a speaker or acoustic module. The audio output **308** may include sounds or audio signals that are associated with the operation of the device. For example, the audio output **308** may correspond to the operation of an input device to provide audio feedback to the user. For example the audio output **308** may correspond to an input received in the form of a force input **302**, touch input **306**, and/or button/dial input **310**. In some cases, the audio output **308** may also include a portion of an auditory alert that may be produced alone or combined with a haptic output **312** and/or display output **304** of the device **100**.

The device **100** may also include a sensor input **318** produced using one or more sensors that may be configured to monitor and detect various environmental conditions. For example, the sensor input **318** may include signals or data produced using an ambient light sensor, proximity sensor, temperature sensor, barometric pressure sensor, or other sensor for monitoring environmental conditions surrounding or near the device. In general, the sensor input **318** may be used to adapt the functionality of the device **100** to conform to the one or more environmental conditions. For example, the brightness of the display output **304**, the volume of the audio output **308**, and/or the operation of the input to the device **100** may be based on the sensor input **318**.

In some embodiments, the sensor input **318** includes input produced by one or more motion sensors. The motion sensors may include one or more of the following: an accelerometer, a gyroscope, a tilt sensor, or other type of inertial measurement device. A sensor input **318** produced using one or more motion sensors may be used to monitor and detect changes in motion of the device **100**. Changes in linear and angular motion may be used to determine or estimate an orientation of the device relative to a known location or fixed datum. The sensor input **318** produced from the one or more motion sensors may also be used to track the movement of the user. The movement of the user may be used to facilitate navigation or map-guided functionality of the device. Additionally, input related to the gross movement of the user can be used as a pedometer or activity meter, which may be stored and tracked over time to determine health metrics or other health-related information. Additionally, in some embodiments, sensor input **318** from the one or more motion sensors may be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty).

The device **100** may also include a biosensor input **320** produced using one or more biosensors or biosensor modules that are configured to monitor physiological and/or health conditions of a user. As discussed above with respect to FIG. **2**, the device may include one or more optical sensors for measuring heart rate, blood pressure, oxygen saturation, or a combination thereof. The device may also include one or more sensors having electrical contacts that are disposed to contact the user's body. The sensors may be configured to measure electrocardiographic (ECG) characteristics, galvanic skin resistance, and other electrical properties of the user's body. Additionally or alternatively, sensors may be configured to measure body temperature, exposure to UV radiation, and other health related information. The biosensor input **320** may be combined with other aspects of the device to provide heath-monitoring functionality. For example, the biosensor input **320** may be used to compute data that is presented using the display output **304**. The operation of the biosensor input **320** may also be controlled using the force input **302**, touch input **306**, or other user input **310** to provide an interactive health monitoring function or application.

As shown in FIG. **3**, the device may include a haptic output **312** that may be produced using one or more haptic devices that are configured to provide haptic feedback to the user. In particular, the haptic output **312** may be produced using one or more electromechanical subassemblies that are configured to induce motion or vibration in the device, which may be perceived or sensed by the user. In some cases, the haptic actuator or device is tuned to operate based on a resonance or near resonance with respect to the device, which may enhance haptic output. In some cases, the haptic actuator or device is configured to operate based on a resonance or near resonance with respect to some components of the device, such as the band or clasp of the device.

In some embodiments, the haptic output **312** may correspond to the operation of one or more other modules or subsystems. For example, the haptic output **312** may include a vibration or haptic feedback that corresponds to an audio alert or visual alert or signal produced by the acoustic module or display, respectively. Additionally or alternatively, the haptic output **312** may be operated in conjunction with an input from the user. The haptic output **312** may include haptic or force feedback that confirms that the user input was or is being received. By way of example, a haptic output **312** may include a click or vibration when the crown of the device is turned or a button is depressed. The haptic output **312** may also be coordinated with other functionality of the device including, for example, message transmission operations, power management operations, force sensor operations, biosensor operations, to provide a notification, to provide an alert, and others.

As shown in FIG. **3**, the device **100** may also include communications input/output (I/O) **316**, which may facilitate communication with an external device or system. The communications I/O **316** may be produced using one or more wireless interfaces, including radio frequency cellular interfaces, fiber optic interfaces, acoustic interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. In some cases, the communications I/O **316** may include signals and data received from an external device that has been paired or is otherwise in electronic communication with the device **100**. The external data included in the communications I/O **316** may include, for example, message data associated with an electronic communication, notification data associated with an event, and/or data related to audio or visual content. The communications I/O **316** may also include an authorization or identification of external devices in communication with the device **100** or users associated with one or more external devices. Similarly, the communications I/O **316** may be used to output various forms of data or signals to one or more devices or systems that are external to the device **100**. For example, the communications I/O **316** may include data or computations that are produced using the biosensor input **320** and/or the sensor input **318**.

FIG. **4** depicts an example wearable electronic device **100** as part of a system of devices. By way of example, the wearable electronic device **100** of FIG. **4** may correspond to the devices shown in any of the previous figures. Generally, the wearable electronic device **100** may communicate wirelessly with any of a number of other devices, such as mobile phone **420**, computer **430**, tablet computing devices, personal media players, televisions, networked home appliances, networked home controls, electronic systems in vehicles, and so on. Additionally, the wearable electronic device **100** may communicate wirelessly with any of a number of electronic accessories, including headset devices, portable speaker devices, portable microphone devices, display screens, and so on. Communication may be through a wired or wireless connection, including any technology mentioned herein.

In some embodiments the wearable electronic device **100** may accept a variety of bands, straps, or other retention mechanisms (collectively, “bands”). These bands may be removably connected to the electronic device by a feature formed into the band or band assembly that is accepted in a recess or other aperture within the device and locks thereto. An example band interface is described in more detail below with respect to FIGS. **25**A-C.

In general, a user may change combinations of bands and electronic devices, thereby permitting mixing and matching of the two categories. It should be appreciated that devices having other forms and/or functions may include similar recesses and may releasably mate with a lug and/or band incorporating a lug. In this fashion, a system of bands and devices may be envisioned, each of which is compatible with another. A single band may be used to connect to devices, as one further example; in such embodiments the band may include electrical interconnections that permit the two devices to transmit signals to one another and thereby interact with one another.

Insofar as the electronic device **100** may connect either physically or through a data communication link with other computing devices, the combination of devices and bands may be thought of as an ecosystem having multiple parts that interact with one another, may intelligently communicate with one another, may share functionality and/or may substitute for one another in terms of operations, output, input and the like. Examples of devices existing in such an ecosystem follow, but are illustrative rather that limiting.

As one example, a number of electronic devices **100**, **420**, **430** may each have identical or similar attachment structures that permit them to share a band or connector. A user may thus change the interconnected band and device(s) with respect to one another, permitting a number of different physical connections between different ecosystem components. In some embodiments, a band that serves to retain an electronic device only may be swapped for bands having additional functionalities, such as transmitting data between devices connected to the band, adding functionality to a connected device that the device lacks, providing additional power to a connected device, and so on. Further, different bands may look different, so that the appearance of the electronic device(s) in combination with a band(s) may change by changing the band(s) and/or device(s) with respect to one another.

As another example, electronic devices **100**, **420**, **430** may communicate with one another as part of the overall ecosystem. Data may be passed from one device **420** to another 100. This may be useful if the user **410** is wearing one electronic device **100** but is not near another device **430** that wishes to notify the user or interact with the user in some fashion. Continuing the example, the computer **430** may transmit a reminder or message to the wearable device **100** to gain the user’s attention. As another example, the computer **430** (or any other electronic device in the ecosystem) may transmit a state of an application or even the device itself to the wearable device **100**. Thus, for example, if an application operating on the computer needs the user’s attention, it may be gained through an alert issued by the wearable device.

Data communication between devices in an ecosystem may also permit the devices to share functionality. As one

non-limiting example, electronic devices may share sensor data with one another to permit one device access to data it normally would not have, from a sensor it does not physically incorporate. Thus, any given device **100**, **420**, **430** may draw on the abilities of other devices in the ecosystem to provide an enhanced and relatively seamless experience for a user **410**.

FIG. **5** depicts a system **500** of interchangeable components for a wearable device. By way of example, one or more of the devices of FIG. **5** may correspond to the devices shown in any of the previous figures. FIG. **5** depicts a system **500** including a variety of interchangeable components, including multiple device bodies **515**, **525**, **535** that are configured to connect via a standard interface to any one of a number of different bands **551***a-b*, **552***a-b*, **553***a-b*, **554***a-b*, and **555***a-b*. In addition, each of the three devices may be configured to connect via a standard interface to another type of non-band component, such as a lug **556***a-b*, non-band component, or other device.

As shown in FIG. **5**, the system **500** may include a body or device that is adapted to attach to one or more bands, straps, or other similar component that may be used to attach the device to the body of a user. In some embodiments, the device may be interchangeable or interchanged to provide a different set of functions or features. In some embodiments, the bands or attachment components may be interchangeable or interchanged to provide desired functionality or features.

In the example depicted in FIG. **5**, each of the devices includes at least one receiving feature **504** that is configured to interconnect with a corresponding feature **502** that is attached to or integrally formed with the end of each of the bands or other mating parts. In some embodiments, receiving feature **504** includes a channel or groove that is formed in one end of the device body. The mating feature **502** of a respective band or component may be configured to slidably engage with the receiving feature **504** of a respective device body to attach the band or component. An example receiving feature is described in more detail below with respect to FIGS. **25**A-C. In some embodiments, the receiving feature **504** and the mating feature **502** are standardized in the system **500** and, thus, any of the bands (**551***a-b*, **552***a-b*, **553***a-b*, **554***a-b*, and **555***a-b*) can be interchangeably used with any of the device bodies **515**, **525**, **535**.

With respect to FIG. **5**, each of the bands may be formed from a different material or using a different construction. In the present example, bands **551***a-b* may be formed from a textile material that may be constructed from a pattern of thread or fiber material. The textile material may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **552***a-b* may be formed from a woven material and may be constructed from an array of warp fibers or threads interwoven with one or more weft fibers or threads. Similarly, the warp and weft fibers may include a variety of materials, including natural fibers, synthetic fibers, metallic fibers, and so on. The bands **553***a-b* may be formed from leather material **553***a-b*. In one example, the bands **553***a-b* are formed from a sheet or strip of cowhide; however, the bands **553***a-b* may also be formed from one of any number of types of animal hide. The leather material **553***a-b* may also include a synthetic leather material, such as vinyl or plastic. The bands **554***a-b* may be formed from a metallic mesh or link construction. For example the bands **554***a-b* may be formed from a Milanese mesh or other similar type of construction. The bands **555***a-b* may be formed from a silicone or other elastomer material.

In some cases, the band is a composite construction including various materials, which may be selected based on the end use or application. In some embodiments, a first band strap, or a first portion of the first band strap, may be made up of a first material and a second band strap, or a second portion of the second band strap, may be made from a second, different material. The band may also be made up of a plurality of links and, as such, the band may be resizable by, for example, adding or removing links. Example bands and band constructions are provided below in Section **12**.

In the system **500**, an interchangeable band may allow for individual customization of the device or to better adapt the device for a range of uses or applications. In some instances, the type of band that is selected and installed can facilitate a particular user activity. For example, band **551***a-b* may be formed from a textile material and include a durable clasp that may be particularly well suited for exercise or outdoor activities. Alternatively, as discussed above the band **554***a-b* may be formed from a metallic material and include a thin or low-profile clasp that may be well suited for more formal or fashion-focused activities.

In some embodiments, the band may be coupled to a separate component having the mating feature **502**. The band may be coupled using pins, holes, adhesives, screws, and so on. In yet other embodiments, the band may be co-molded or overmolded with at least a portion of the component having the mating feature **502**. In some embodiments, the band is coupled to the component via a pin that allows the straps to rotate with respect to the component. The pin may be formed integrally with or disposed in a loop formed in the end of the band.

In the example system **500**, each of the bands is shown as having a generic band clasp. However, the type of band clasp that is used may vary between embodiments. On example band clasp may include a first band strap having a buckle or tang assembly which is configured to interface with a second band strap having a series of apertures or holes formed with the strap. Additionally or alternatively, the bands may include a magnetic clasp having one or more magnetic elements on a first band strap that is configured to mate to one or more magnetic or ferromagnetic elements on a second band strap.

As shown in FIG. **5**, the system may include multiple device bodies **515**, **525**, **535** that may vary in size, shape, and composition. The device body **515**, **525**, **535** may include one or more of the embodiments described herein and may include, but is not limited to a wearable computer, a wearable watch, a wearable communication device, a wearable media player, a wearable health monitoring device, and/or the like. In particular, the device body may correspond to the device body described with respect to device body **610** of device **100** (shown in FIG. **6**).

1. Example Wearable Electronic Device

FIG. **6** depicts an example wearable electronic device, which may include various aspects of the device(s) described above. In some embodiments, multiple modules or subsystems are physically and operationally integrated together to provide particular functionality or device features. In particular, the interaction between the subsystems, or the subsystems themselves, may be configurable by the user, manufacturer, or vendor to adapt the device to produce certain functionality. Some example combinations and interactions between the various modules and subsystems are expressly provided in the present description. However, the combinations and interactions provided herein are merely illustrative in nature and are not intended to be limiting on the scope of the disclosure.

FIG. **6** depicts an example configuration of a wearable electronic device **100**. In particular, FIG. **6** depicts an electronic wearable device **100** including a device body **610** that may be configured to be attached to the wrist of a user using a band assembly **620**. This configuration may also be referred to herein as a wearable device, a device, an electronic wristwatch, or an electronic watch. While these terms may be used with respect to certain embodiments, the functionality provided by the example electronic wearable device **100** may be substantially greater than or vary with respect to many traditional electronic watches or timekeeping devices.

In the present example, the exterior surface of the device body **610** is defined, in part, by the exterior surface of the housing **601** and the exterior surface of the cover **609**. In the example depicted in FIG. **6**, the device body **610** is substantially rectangular with round or curved side portions. The outer surfaces of the cover **609** and the housing **601** coincide at a joint interface and cooperate to form a continuous contoured surface. The continuous contoured surface may have a constant radius and may be tangent to a flat middle portion of the cover **609** and/or a flat bottom portion of the housing **601**. In some embodiments, the cover **609** has substantially the same shape as a flat bottom portion and at least a portion of the curved side portions of the housing **601**. A more complete description of the geometry of the cover **609** and the housing **601** is provided below with respect to FIGS. **7** and **8**.

In the example of FIG. **6**, the device **100** includes a display (item **120** of FIG. **2**) that is disposed at least partially within an opening or cavity defined within a top portion of the housing **601** of the device body **610**. The display may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user and may be operated in accordance with one or more display modes or the software applications being executed on the device **100**. By way of example, the display may be configured to present the current time and date similar to a traditional watch or timepiece. The display may also present a variety of other visual information that may correspond to or be produced using one of the other modules in the device **100**. For example, the display may be configured to display one of a variety of notification messages, which may be generated based on data received from the one or more sensors, the wireless communication system, or other subsystem of the device **100**. The display may also be configured to present visual information or data that is based on the output of one or more sensor outputs. The display may also provide status or information related to a wireless charging process or battery power. The display may also present visual output or information related to media being produced using a speaker or acoustic module of the device **100**. Accordingly, a variety of other types of visual output or information may be presented using the display.

In the current example, the display includes or is integrated with a cover **609** that helps to protect the display from physical impact or scratches. In the field of wearable devices, the cover **609** may also be referred to generically as a crystal or cover glass, regardless of the material that is used to form the cover **609**. In some cases, the cover **609** is formed from a sheet or block of sapphire material. Sapphire may provide superior optical and surface hardness properties as compared to other materials. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. In alternative embodiments, the cover **609** is formed from a glass, polycarbonate, or other optically transparent material. The cover **609** may also be coated with one or more optical or mechanical enhancing materials or surface treatments. For example, interior and/or exterior surfaces of the cover **609** may be coated with an anti-reflective (AR), oleophobic or other coating to enhance the visible or functional properties of the display. Additionally, in some cases, the cover **609** may be configured to cooperate with an antenna used to facilitate wireless communication with an external device. FIGS. **21**A-B, described in more detail below, provide one example embodiment of a cover configured to cooperate with an antenna.

In the example depicted in FIG. **6**, the cover **609** is formed from a transparent material and, when assembled has an external surface and an internal surface. The cover **609** is disposed above the display and encloses a cavity or opening formed in the top portion of the housing **601**. In some embodiments, the external surface of the cover **609** cooperates with the external surface of the housing to form a substantially continuous external peripheral surface of the electronic device. As shown in FIG. **6**, the external surface of the cover **609** has a flat middle portion at the center of the cover, which extends outwardly. The cover **609** also includes a curved edge portion that emanates from and surrounds the flat middle portion and extends outwardly to an edge at the side of the cover **609**. In some embodiments, the cover **609** also includes an opaque mask disposed relative to the internal surface of the transparent cover. The opaque mask may correspond to or otherwise define the viewable area of the display **120**. The mask may have an outer boundary that is located proximate the edge of the side of the cover **609** and has an inner boundary located within the curved edge portion of the cover **609**.

As shown in FIG. **6**, the cover **609** is disposed relative to a top portion of the housing **601**. The housing **601** includes a top portion defining an opening, which is surrounded by a curved side portion. In the present example, the curved edge portion of the cover **609** coincides with the curved side portion of the housing **601** to form a continuous external surface of the electronic device **100**. In some instances, the cover **609** may have a contour that follows or otherwise corresponds to a similar contour of the housing **601** to form a substantially continuous surface at the interface between the two components. As shown in FIG. **6**, the cover **609** protrudes above the housing **601**.

In some instances, the cover **609** is disposed relative to a touch sensor (item **702** of FIG. **7**). In some embodiments, the touch sensor may be integrated with the display or other element of the device **100**. The touch sensor may be formed from one or more capacitive sensor electrodes or nodes that are configured to detect the presence and/or location of an object or the user's finger that is touching or nearly touching the surface of the display. In some cases, the touch sensor includes an array of sensing nodes formed in accordance with a mutual capacitance sensing scheme.

In one example, the touch sensor may include an array of mutual capacitance touch nodes that can be formed by a two-layer electrode structure separated by a dielectric material. One layer of electrodes may comprise a plurality of drive lines and another layer of electrodes may comprise a plurality of sense lines, and where the drive lines and the sense lines cross, mutual capacitive sense nodes are formed (also referred to as coupling capacitance). In some implementations, the drive lines and sense lines may cross over each other in different planes separated from one another by a dielectric. Alternatively, in other embodiments the drive lines and sense lines can be formed substantially on a single

layer. An example touch sensor and touch-sensing node are described in more detail below with respect to FIGS. **14**A-C and **15**A-B.

Alternatively or additionally, the touch sensor may include one or more self-capacitive nodes or electrodes that are configured to detect a discharge of electrical current or charge when an object, such as a user's finger, contacts or nearly contacts a surface of the housing **601** or other surface of the device **100**. Other types of electronically sensing nodes, including resistive, inductive, or the like, may also be integrated into a surface of the device **100**.

In some embodiments, the device **100** may also include a force sensor (item **705** of FIG. **7**). The force sensor may be disposed relative to the display **120** or integrated with other elements of the device **100**. In some cases, the force sensor includes one or more force sensing structures or force-sensing nodes for detecting and measuring the magnitude of a force or pressure due to a touch on a surface of the device **100**. The force sensor may be formed from or implement one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a force or pressure due to a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on the deflection. Example force sensor and force-sensing modules are described in more detail below with respect to FIGS. **9-12**.

As shown in FIG. **6**, the device **100** also includes device body **610** including a housing **601** that upon which may be mounted or integrated with various components of the device **100**. The housing **601** serves to surround at a peripheral region as well as support the internal components of the product in their assembled position. In some embodiments, the housing **601** may enclose and support internally various components (including for example integrated circuit chips and other circuitry) to provide computing and functional operations for the device **100**. The housing **601** may also help define the shape or form of the device. That is, the contour of the housing **601** may embody the outward physical appearance of the device. As such, it may include various ornamental and mechanical features that improve the aesthetical appearance and tactile feel of the device. For example, the housing **601** may include a contoured surface that includes rectilinear contours, curvilinear contours, or combinations thereof. The housing **601** may also include various surface features, including textures, patterns, decorative elements, and so on.

In the present example, the housing **601** is formed from a single piece, which may also be referred to as single-body, unitary, or uni-body design or construction. By utilizing a single-body construction, the structural integrity of the device may be improved as compared to a multi-piece construction. For example, a single body may be more easily sealed from contaminants as compared to a multi-piece enclosure. Additionally, a single-body enclosure may be more rigid due, in part, to the absence of joints or seams. The rigidity of the housing **601** may be further enhanced by increasing the material thickness in areas where mechanical stress may be greatest, while also maintaining or thinning other areas where mechanical stress may be lower or reduced. Variations in the thickness of the housing **601** may be possible by machining or casting the housing **601** as a single piece. Additionally, a single-body housing **601** may include one or more features for mounting or integrating the internal components of the device **100**, which may facilitate manufacturing and/or assembly of the device **100**.

An example housing **601** is described in more detail below with respect to FIG. **8**. The housing **601** may be formed from a variety of materials, including, without limitation plastic, glass, ceramics, fiber composites, metal (e.g., stainless steel, aluminum, magnesium), other suitable materials, or a combination of these materials. Further, the housing **601** may include a surface treatment or coating, which may be formed from a variety of materials, including, without limitation aluminum, steel, gold, silver and other metals, metal alloys, ceramics, wood, plastics, glasses, and the like.

As discussed above, the display, the touch sensor, and force sensor may be disposed within the housing **601**. In this example, one or more buttons **644** and a crown **642** used to receive user input may also be disposed within or relative to the housing **601**. Other types of user input, including for example, one or more dials, slides, or similar user input devices or mechanisms may also be disposed within or relative to the housing **601**. As described in more detail with respect to FIGS. **7** and **8**, the housing **601** may include various features for attaching and mounting the subassemblies and modules of the device **100**. In particular, the housing **601** may have one or more openings for receiving the cover **609**, the display, the force sensor, or other components. The housing **601** may also include one or more holes or openings for receiving the button **644** and crown **642** that are located around the perimeter of the device **100**. In some embodiments, the housing **601** also includes internal features, such as bosses and threaded portions, that can be used to attach modules or components within the housing **601**.

The device **100** may also include an ambient light sensor (ALS) that is configured to detect and measure changes in ambient lighting conditions. The ALS may include a photodiode and one or more optical elements or lenses for collecting light. An ALS may be located on an external facing surface that is less likely to be blocked when the device is worn or in use. The ALS may be used to adjust settings, including screen brightness and other visual output depending on the overall lighting conditions.

The housing **601** may also include one or more motion-sensing elements or devices for detecting motion of the device **100**. For example, the device **100** may include one or more accelerometers that are configured to sense acceleration or changes in motion. Additionally or alternatively, the device **100** may include one or more gyroscopic sensors that are configured to detect changes in direction. In some cases, the one or more gyroscopic sensors may include a spinning mass that can be used to detect changes in angular velocity. Multiple motion-sensing elements may be used to detect motion along multiple directions or axes. The motion sensors may also be used to identify motion gestures. For example, the motion sensors can be used to detect an arm raise or the position of a user's body (within a predetermined confidence level of certainty). The one or more motion-sensing elements may be used to determine an orientation of the device relative to a known or fixed datum. For example, the device may include a compass and/or global positioning system (GPS) that can be used to identify an absolute position. The one or more motion sensing elements may then measure deviation or movement with respect to the absolute position to track movement of the device or the user wearing the device. In some implementations, the one or more motion-sensing elements are used to detect gross movement of the device or user. The gross movement may be used as

a pedometer or activity meter, which may be tracked over time and used to calculate a health metric or other health-related information.

Described in more detail with respect to FIG. **8**, the housing **601** may also include one or more openings or orifices coupled to an acoustic module or speaker **122**, which may include a speaker and/or a microphone subassembly. Although the housing **601** may include one or more openings or orifices, the housing **601** may still be substantially waterproof/water resistant and may be substantially impermeable to liquids. For example, the opening or orifice in the housing or enclosure may include a membrane or mesh that is substantially impermeable to liquid ingress. Additionally or alternatively, the geometry of the opening or orifice and other internal features of the housing **601** may be configured to reduce or impede the ingress of liquid or moisture into the device **100**. In one example, the opening is formed from one or more orifices that are offset with respect to an internal acoustic chamber or cavity, which may prevent a direct path from the outside of the housing **601** into the acoustic module.

As shown in FIG. **6**, the device **100** includes a device body **610** that may be attached to a user's wrist using a band **620**. In the present example, the band **620** include a first band strap **621** attached to a first receiving feature **623** and a second band strap **622** attached to a second receiving feature **624**. In some embodiments, the first and second band straps **621**, **622** include a lug feature that is configured to attach to the first and second receiving features **623**, **624**, respectively. As shown in FIG. **6**, the free ends of the band straps **621**, **622** are connected with a clasp **625**.

The band straps **621**, **622** are formed from a flexible or compliant material that may be specially configured for a particular application. The band straps **621**, **622** may be formed from a variety of materials, including, for example, leather, woven textiles, or metallic mesh materials. The material and construction of the band straps **621**, **622** may depend on the application. For example, the band straps **621**, **622** may be formed from a woven textile material configured for exposure to impact and moisture typically associated with outdoor activities. In another example, the band straps **621**, **622** may be formed from a metallic mesh material that may be configured to have a fine finish and construction that may be more appropriate for professional or social activities.

Similarly, the clasp **625** of the band **620** may be configured for a particular application or to work with a particular style of band. For example, if the band straps **621**, **622** are formed from a metallic mesh material, the clasp **625** may include a magnetic clasp mechanism. In the present example, the device **100** is configured to be attached to the wrist of a user. However, in alternative embodiments, the device may be configured to be attached to the arm, leg or other body part of the user.

The housing **601** includes one or more features for attaching the band straps **621**, **622**. In the present example, the housing **601** includes a first receiving feature **623** and a second receiving feature **624** for attaching the first band strap **621** and the second band strap **622**, respectively. In this example, the band straps **621**, **622** include a lug portion that is adapted to mechanically engage with the receiving features **623**, **624**. A more detailed description of the receiving features and lugs is provided below with respect to FIGS. **25**A-C. As shown in FIG. **6**, the first **623** and second receiving features **624** may be integrally formed into the housing **601**. In alternative embodiments, the receiving features may be formed from separate parts and may be attached to the housing **601** during manufacturing. In some embodiments, the receiving features **623**, **624** may be configured to release the band straps **621**, **622** from the device body **610** (e.g., the housing **601**). For example, one or both of the receiving features **623**, **624** may include a button or slide, which may be actuated by the user to release a corresponding band strap **621** and **622**. One advantage of a releasable lug is that the user can swap between a variety of bands that may be specially configured for a particular use scenario. For example, some bands may be specially configured for sport or athletic activities and other bands may be configured for more formal or professional activities.

The device **100** may also include a rear cover **608** located on the rear-facing surface of the housing **601** of the device body **610**. The rear cover **608** may improve the strength and/or scratch resistance of the surface of the device **100**. For example, in some embodiments, the rear cover **608** may be formed from a sapphire sheet, zirconia, or alumina material having superior scratch resistance and surface finish qualities. In some cases, the sapphire material has a hardness greater than 6 on the Mohs scale. In some cases, the sapphire material has a hardness of approximately 9 on the Mohs scale. Due to the superior strength of the sapphire material, a cover glass formed from a sapphire sheet may be very thin. For example, the thickness of a sapphire cover sheet may be less 300 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 100 microns thick. In some cases, the thickness of a sapphire cover sheet may be less than 50 microns thick. In some embodiments, the rear cover **608** is contoured in shape. For example, the rear cover **608** may have a convex curved surface.

FIG. **7** depicts an example exploded view of various modules and subassemblies of the device **100**. As shown in FIG. **7**, multiple components are configured to be disposed within and/or attached to the housing **601**. The exploded view provided in FIG. **7** depicts one example arrangement of the components of the device **100**. However, in other embodiments, arrangement, placement, and/or grouping of the subassemblies and the components of the subassemblies may vary.

In the present example, a main cavity of the housing **601** houses an electronics subassembly **720** and the battery **114** of the device. The electronics subassembly **720** includes one or more electrical circuit assemblies for coupling the various electrical components of the device **100** to each other and to power supplied by the battery **114**. The electronics subassembly **720** may also include structural elements or components that provide structural rigidity for the electronics subassembly **720** and/or structural mounting or support for other components disposed within the housing **601**. As shown in FIG. **7**, within the cavity of the housing **601**, the speaker **122**, the crown module **642**, and the battery **114** are all disposed above the electronics subassembly **720**. In the present embodiment the top surface of the speaker **122**, the crown module **642**, and the battery **114** have a substantially similar height. In some embodiments, the speaker **122**, the crown module **642**, and the battery **114**, when assembled in the housing **601**, define an area for the display **120** within the cavity. Thus, as shown in FIG. **7**, the display **120** may overlay the speaker **122**, the crown module **642**, and the battery **114**, which overlay the electronics subassembly **720**.

As shown in FIG. **7**, the cover **609** is configured to fit within a corresponding recess formed within the housing **601**. In particular, the cover **609** includes a vertical portion having a height that corresponds to the depth of the recess formed within the housing **601**. In this example, the device **100** includes a force sensor **705** disposed between the housing **601** and a cover subassembly **704**. As described in

more detail below with respect to FIGS. **9** and **10**A-B, the force sensor **705** may be configured to detect a force placed on a surface of the cover **609** by detecting a relative deflection between the cover **609** (or cover subassembly **704**) and the housing **601**. In the present example, the force sensor **705** also forms a gasket or seal between the cover subassembly **704** and the housing **601**. In some implementations, the seal is a water-proof or water-resistant seal that helps to prevent water or liquid ingress into the internal cavity of the housing **601**. The force sensor **705** may also be used to join the cover subassembly **704** to the housing **601** using an adhesive or film.

In some embodiments, the cover subassembly **704** includes the cover **609** which is disposed above the touch sensor **702** and display **120**. In the present example, the touch sensor **702** and the display **120** are attached to each other by an optically clear adhesive layer (OCA). Similarly, an OCA layer is used to attach the touch sensor **702** to the cover **609**. Other adhesives or bonding techniques may be used to attach the display **120** and the touch sensor **702** to the cover **609**. In some embodiments, the touch sensor **702** is integrated into the display **120** and the display **120** (and integrated touch sensor **702**) are attached to the cover **609**.

As shown in FIG. **7**, the speaker **122** is also disposed within the cavity of the housing **601**. The speaker **122** is adapted to mechanically and acoustically interface with a port formed in the side of the housing **601**. In some embodiments, the port is configured to prevent a direct path for water or liquid into an acoustic chamber or cavity of the speaker **122**. In some embodiments, the device **100** also includes a microphone that is similarly coupled to another port formed in the side of the housing **601**. A more detailed description of the speaker **122** and microphone is provided below with respect to the acoustic module of FIG. **20**.

In the present example, the haptic device **112** is also disposed within the cavity of the housing **601** proximate to the speaker **122**. In some embodiments, the haptic device **112** is rigidly mounted to a portion of the housing **601**. A rigid mounting between the housing **601** and the haptic device **112** may facilitate the transmission of vibrations or other energy produced by the haptic device **112** to the user. In the present example, the haptic device **112** includes a moving mass that is configured to oscillate or translate in a direction that is substantially parallel with a rear face of the housing **601**. In some implementations, this orientation facilitates the perception of a haptic output produced by the haptic device **112** by a user wearing the device **100**. While this configuration is provided as one example, in other implementations, the haptic device **112** may be placed in a different orientation or may be configured to produce a haptic response using a rotating mass or other type of moving mass.

As shown in FIG. **7**, the device also includes an antenna subassembly **722**. In this example, a portion of the antenna subassembly **722** is disposed within the housing **601** and a portion of the antenna subassembly **722** is disposed within the cover assembly. In some implementations, a portion of the antenna subassembly **722** is disposed relative to a feature formed within the cover **609**. An example embodiment is described in more detail below with respect to FIGS. **21**A-B.

In the example depicted in FIG. **7**, the device **100** also includes a crown module **642** which is disposed in an aperture or hole in the housing **601**. When installed, a portion of the crown module **642** is located outside of the housing **601** and a portion of the crown module **642** is disposed within the housing **601**. The crown module **642** may be configured to mechanically and/or electrically cooperate with the electronics subassembly **720**. A more detailed description of an example crown module is provided below with respect to FIGS. **23** and **24**A-B. The housing **601** also includes a button **644**, which is disposed in an opening of the housing **601** and may be configured to mechanically and/or electrically cooperate with the electronics subassembly **720**.

In the example depicted in FIG. **7**, a biosensor module **710** is disposed in an opening formed in the rear surface of the housing **601**. In some embodiments, the biosensor module **710** includes the rear cover **608** and may also include a chassis or plate that facilitates attachment of the biosensor module **710** to the housing **601**. The chassis or plate or the cover sheet **608** may also include features or elements that facilitate a watertight seal between the biosensor module **710** and the housing **601**. For example, the rear cover **608** may include a shelf or flange that may be used to form a seal between the biosensor module **710** and the housing **601**. As described in more detail below with respect to FIG. **16**, the biosensor module **710** may include one or more light sources, one or more photodetectors, and one or more electrodes or conductive elements that are configured to detect and measure a physiological condition or property of the user.

In some embodiments, the rear cover **608** has an edge that protrudes outwardly from the back surface of the housing **601**. The rear cover **608** may also have a convex curved area located between the edges of the rear cover **608**. The convex curved area of the rear cover **608** may include one or more windows or apertures that provide operational access to one or more internal components located within the housing **601**. In some embodiments, the windows have a curvature that matches the curvature of the convex curved area of the rear cover.

2. Example Housing

As described above, a wearable electronic device may include a device body that includes a housing or enclosure shell. As previously described, the housing may function as a chassis that physically integrates the various components of the device. The housing may also form a protective shell or housing for the components and function as a barrier against moisture or debris. In the present examples, the housing is formed as a uni-body, unitary, or single body or component. A single-body construction may be advantageous by providing mounting features directly into the housing, which may reduce space, reduce part count, and increase structural rigidity as compared to some alternative configurations. Additionally, a single-body construction may improve the housing's ability to prevent the ingress of moisture or debris by reducing or eliminating seams or joints between external components.

FIG. **8** depicts an example housing **601** in accordance with some embodiments. In the present example, the housing **601** is formed as a single body or component. As shown in FIG. **8**, the housing **601** is formed as a single part or body. The housing **601** may be formed, for example, by machining or shaping a solid or cast blank having the approximate shape of the housing **601**. In some implementations, the housing **601** may be configured to provide structural integrity for potentially delicate internal components and also withstand a reasonable impact.

In the present embodiment, the housing **601** is formed as a uni-body, unitary, or single-body construction having a flat bottom portion **801** and a top portion including flange **812**. The top portion defines an internal cavity **805**, which is surrounded by four sides **802***a-d* that are integrally formed with the bottom portion **801**. The internal cavity **805** can also be described as being defined by the top portion, the four

sides **802**a-d and the bottom portion **801**. In this example, the internal cavity **805** has a rectangular (square) shape, although the specific shape may vary with different implementations. In the present example, the four sides **802**a-d define a curved side portion of the housing **601** that extends from the bottom portion **801** to the top portion of the housing **601**. Each side **802**a-d is orthogonal to an adjacent side and each side **802**a-d is connected to an adjacent side by a rounded corner. For example, side **802**a is orthogonal to two adjacent sides **802**b and **802**d and is connected to those sides by respective rounded corners. The shape or contour of the rounded corners may correspond to the curvature of the curved portion of the housing **601**. Specifically, the curvature of the rounded corners may match or correspond to the curvature of the continuous external surface formed by the housing **601** and the cover **609**, as described above with respect to FIG. **6**.

The sides **802**a-d may vary in thickness in order to provide the structural rigidity for the device. In general, areas of high stress may have an increased material thickness as compared to areas of low stress, which may have a reduced material thickness. In particular, portions of the sides **802**a-d near the bottom portion **801** may have an increased thickness as compared to portions of the sides **802**a-d located further away from the bottom portion **801**. This configuration may improve the structural rigidity and overall stiffness of the housing **601**.

As shown in FIG. **8**, one or more mounting features may be formed directly into the housing **601**, which may reduce the number of parts and also enhance the structural integrity of the device. As shown in FIG. **8**, receiving features **623**, **624** may be formed as channels or openings that are configured to receive an end of a band (e.g., a lug) having a mating feature. As described above with respect to FIG. **5**, the receiving features **623**, **624** may be standardized and configured to work with a system of interchangeable components. Forming the receiving features **623**, **624** directly into the housing **601** may reduce parts and also facilitate structural rigidity of the device.

In the example depicted in FIG. **8**, the housing **601** can be described as having two ends (a first end and a second end opposite the first end), and a first side and a second side opposite the first side, the sides being continuous with the ends. In this example, the first and second ends and the first and second sides having an outwardly curved three-dimensional shape. In this example, the receiving feature **623** is formed from a first groove situated in the first end. Similarly, the receiving feature **624** is formed from a second groove situated in the second end. In the present example the grooves have openings at the interface of the first and second sides and first and second ends. As shown in FIG. **8** the groove also has an inwardly curved concave three-dimensional shape with an undercut feature. For example, the middle portion of the groove of receiving features **623**, **624** may have a width that is greater than the opening of the receiving features **623**, **624**. In some embodiments, the upper portion of the housing overhangs the lower portion of the housing at the groove opening. In the example depicted in FIG. **8**, the groove is cut into a solid portion of the housing such that the groove forms a continuous interior shape.

The geometry of the receiving features may be located with respect to other features or components of the device. In the example depicted in FIG. **8**, at least a portion of the groove of the receiving features **623**, **624** may be disposed underneath the cover (item **609** of FIGS. **6**-**7**). With respect to FIG. **6**, the groove of the receiving features **623**, **624** is located underneath the opening for the cover, which is defined by the sealing ledge **810** and flange **812** formed in the upper portion of the housing **601**. In some embodiments, the length of the groove extends further than the width of the opening configured to receive the cover (and thus the cover, when assembled). In some embodiments, the grooves are formed at an angle relative to the centerline of the housing. In some cases, the angle is approximately 5 degrees. In some embodiments, the groove is located underneath the centerline of the housing **601**. In some embodiments, the groove is angled upward toward the top of the housing **601** and inward toward the center of the housing **601**. The groove may angle upward and cross the centerline of the housing. In some cases, the groove crosses the vertical centerline of the housing **601**.

In the present embodiment, the housing **601** also includes an aperture **821** formed into the side **802**c of the housing **601** for attaching a crown or crown module (item **642** of FIGS. **6**-**7**). In some embodiments, the aperture **821** for the crown is offset upwardly from the centerline of the housing **601**. In some embodiments, the aperture **821** for the crown is positioned such that an upper portion of a crown (when installed) is higher than the interface of cover **609** and housing **601**. With respect to FIG. **6**, the interface may correspond to the upper edge of the flange **812**.

The housing **601** also includes an opening **822** formed into the side **802**c of the housing **601** for attaching the button (item **644** of FIGS. **6**-**7**). In some embodiments, the aperture **821** for the crown and the opening **822** for the button are disposed with the length defined by a flat part of the cover. In some embodiments, the aperture **821** for the crown is disposed above the centerline of the housing **601** and the opening **822** for the button is disposed below the centerline of the housing **601**. In some embodiments, the aperture **821** for the crown and the opening **822** for the button are disposed on a curved surface of the housing **601**. The housing **601** may also include various other internal features, including threaded features and bosses, for attaching other internal components of the device.

In some cases, the housing **601** may be formed as a single-piece or integral enclosure shell to enhance the structural rigidity and/or liquid-sealing properties of the device. As described above with respect to FIGS. **6** and **7**, the housing **601** may be integrated with a cover (e.g., crystal) and other external components to provide a substantially sealed housing. In the present embodiment, the housing **601**, includes a sealing ledge **810** formed around the perimeter of the main cavity **805** formed within the housing **601**. In some embodiments, the sealing ledge **810** (and thus the cover when installed) is located in the center of the housing **601**. The sealing ledge **810** may be defined by a substantially flat portion **811** that is adapted to form a seal between the housing **601** and another component (e.g., the force sensor **705** or cover **609** of FIGS. **6**-**7**). The sealing ledge **810** may be formed at a depth that is substantially similar or corresponds to the thickness of the mating cover.

As shown in FIG. **8**, the sealing ledge **810** may also include flange **812** that protrudes from the flat portion and forms a continuous surface with the side walls **802**a-d. In some cases, the flange **812** is configured to cooperate with the cover (item **609** of FIGS. **6**-**7**) to form a substantially continuous surface. In some implementations, the sides **802**a-d and the cover or crystal are configured to cooperate or mechanically interface to improve the strength and the water sealing properties of the device.

As also shown in FIG. **8**, an opening or aperture **815** may be formed in the bottom portion **801** of the housing **601**. In some embodiments, the opening or aperture **815** is located

at the center of the housing **601**. As described above with respect to FIG. **7**, the aperture **815** may be used to integrate a sensor array or other module used to collect measurements that may be used to compute a health metric or other health-related information. The present embodiment may be advantageous by integrating multiple components in a single opening **815**, which may facilitate a water-proof or water-resistant property of the device. Additionally, by integrating a sensor array into a module that attaches via the opening **815**, same housing **601** may be used with a variety of sensing configurations or arrays. For example, the number or sensors or components may be increased or decreased without modifying the housing **601**. This may allow for flexibility in the product development and may facilitate upgrades as new sensing configurations are available.

As previously discussed above with respect to FIGS. **6-7**, the housing **601** may also be configured to serve as a protective housing for one or more acoustic elements, such as a microphone or speaker. Additionally, in some embodiments, the housing **601** may also be configured to inhibit the ingress of foreign particulate or moisture. In particular, the housing **601** may include a speaker port having orifices **831**, **832** that are configured to transmit acoustic signals but also prevent the ingress of liquid or other foreign particulate. In the present example, the speaker port includes orifices **831**, **832** that are offset with respect to an acoustic chamber or cavity to prevent the direct ingress of liquid into the speaker subassembly or acoustic module. In the present example, a shielding or umbrella portion of the housing, which is substantially free of openings, is formed between the orifices **831**, **832**, which helps to prevent the direct ingress of liquid. Similarly, the housing **601** includes a microphone port having orifices **833**, **834** that are offset from a corresponding acoustic chamber or cavity to prevent the direct ingress of liquid into the microphone subassembly or acoustic module.

In the example depicted in FIG. **8**, the orifices **831**, **832** of the speaker port are located on one side of the aperture **821** for the crown and the orifices **833**, **834** for the microphone are located on the other side of the aperture **821**. Both the orifices **831**, **832** of the speaker port and the orifices **833**, **834** for the microphone are located on a curved portion of the housing **601**.

3. Example Force Sensor and Touch Sensor

As discussed previously, a wearable electronic device may include one or more sensors for detecting the location and force of a touch. For the purposes of the following description of the force sensor and touch sensor, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100** including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a force sensor and a touch sensor may be disposed relative to the display of a wearable electronic device for to form a touch-sensitive surface. The following description is provided with respect to individual force and touch sensors that may be used to determine the force and location of a touch, respectively. However, in some embodiments, a single integrated sensor may be used to detect both the force and location of a touch on the device.

In one embodiment, an output from a force sensor may be combined with a touch sensor to provide both location and force of a single touch or of multiple touches on the surface of a device. In an alternative embodiment, a hybrid or integrated force and touch sensor may be used to sense both touch force and location of a single touch or of multiple touches. In either embodiment, by sensing both the force and location of a touch, multiple types of user input may be generated and interpreted. In one example, a first touch may be correlated with a first force and a first touch location or gesture. Based on the magnitude of the force, the first touch may be interpreted as a first type of input or command. A second touch may be sensed as having a second, different force and a similar location or gesture as the first touch. Based in part on the magnitude of the second force, the second touch may be interpreted as a second type of input or command. Thus, a force sensor (alone or in combination with another touch sensor) may be used to produce different responses or outputs depending on the force of the touch.

The one or more force sensors may be formed from or may be implemented as one or more types of sensor configurations. For example, capacitive and/or strain based sensor configurations may be used alone or in combination to detect and measure the magnitude of a touch. As described in more detail below, a capacitive force sensor may be configured to detect the magnitude of a touch based on the displacement of a surface or element on the device. Additionally or alternatively, a strain-based force sensor may be configured to detect the magnitude of a touch based on a deflection of the surface, such as the cover glass.

By way of example, the force sensor may include a capacitive force sensor, which may be formed from one or more capacitive plates or conductive electrodes that are separated by a compressible element or other compliant member. As a force is applied to a surface of the device, the compressible element may deflect resulting in a predictable change in the capacitance between the plates or electrodes. In some implementations, a capacitive force sensor may be formed from transparent materials and disposed over the display. In other implementations, a capacitive force sensor may be formed from non-transparent materials and disposed beneath or around the perimeter of a display.

FIG. **9** depicts a detail cross-sectional view of a portion of a force sensor **900** that may be arranged around the perimeter of a display **120**. As shown in FIG. **9**, a force-sensing structure **901** of the force sensor **900** may be disposed beneath the cover **609** and along the side of an edge or the perimeter of the display **120**. In this example, the force sensor **900** is configured to detect and measure the force of a touch on the surface **911** of the cover **609**. In the present embodiment, a first capacitive plate **902** is fixed with respect to the cover **609**. A second, lower capacitive plate **904** is fixed with respect to the housing **601** and may be disposed on a shelf or mounting surface located along the perimeter of the device. The first capacitive plate **902** and the second capacitive plate **904** are separated by a compressible element **906**.

In the configuration depicted in FIG. **9**, a touch on the surface **911** of the device may cause a force to be transmitted through the cover **609** of the device and to the force sensor **900**. In some cases, the force causes the compressible element **906** to compress, thereby bringing the first capacitive plate **902** and the second capacitive plate **904** closer together. The change in distance between the first and second capacitive plates **902**, **904** may result in a change of capacitance, which may be detected and measured. For example, in some cases, a force-sensing circuit may measure this change in capacitance and output a signal that corresponds to the measurement. A processor, integrated circuit or other electronic element may correlate the circuit output to an estimate of the force of the touch. Although the term “plate” may be used to describe certain elements, such as the capacitive plates or conductive electrodes, it should be

appreciated that the elements need not be rigid but may instead be flexible (as in the case of a trace or flex).

FIG. **10**A depicts an example configuration of the force sensor **1000** having four individual force-sensing structures **1001***a-d* arranged around the perimeter of a display in a device. For the sake of clarity, the crystal, display, and other elements of the device are omitted from the depiction of FIG. **10**A. Each of the force-sensing structures **1001***a-d* may be formed from a pair of capacitive plates separated by a compressible element. Additionally, each force-sensing structure **1001***a-d* may be separated by a small gap at or near the corners of the opening in the housing **601**. In the example depicted in FIG. **10**A, the four individual force-sensing structures **1001***a-d* may each be operatively coupled to force-sensing circuitry that is configured to detect a change in the capacitance of each force-sensing structure **1001***a-d*. Using the example arrangement depicted in FIG. **10**A, the approximate location of the touch may be determined by comparing the relative change in capacitance of each force-sensing structure **1001***a-d*. For example, a change in capacitance of structure **1001***b* that is larger as compared to a change in capacitance of structure **1001***d* may indicate that the touch is closer to structure **1001***b*. In some embodiments, the degree of the difference in the change in capacitance may be used to provide a more accurate location estimate.

While the configuration shown in FIG. **10**A depicts the force-sensing structures as individual elements separated by a small gap, in some embodiments, the force-sensing structure may be formed as a single continuous piece. FIG. **10**B depicts a force sensor **1050** formed as a single force-sensing structure **1051** formed as a continuous part along the perimeter of the display. Similar to the example described above, the force-sensing structure **1051** may be operatively coupled to force sensing circuitry that is configured to detect a change in the capacitance of one or more capacitive elements of the force-sensing structure **1051**. While the force-sensing structure **1051** is formed as a continuous structure, there may be multiple sensing elements (e.g., capacitive plates) that are disposed within the structure at different locations, and which may be configured to detect deflection or compression of the structure over a portion of entire area of the force-sensing structure **1051**. In some embodiments, the force-sensing structure **1051** may also function as a seal or gasket to prevent ingress of moisture or other foreign contaminants into the main cavity of the housing. Additionally, the force-sensing structure **1051** may be integrated with one or more sealing or adhesive layers that also function as a barrier for foreign contaminants.

As mentioned previously, the force sensor may additionally or alternatively include a strain-based sensing configuration. The strain-based sensing configuration may include, for example, a charge-based or resistive sensor configuration. FIG. **11** depicts a cross-sectional view of a device having an example force sensor **1100** that uses one or more force-sensitive films to detect and measure the force of a touch on a surface **1111** of the cover **609**. In this example, the force sensitive film **1102** and **1104** are formed from a transparent material and are disposed relative to a viewable portion of the display **120**. As shown in FIG. **11**, the force sensor **1100** includes a first force-sensitive film **1102** and a second force-sensitive film **1104** that are separated by one or more intermediate layers **1106**. The force-sensitive films **1102**, **1104** may be configured to produce different electrical outputs in response to a strain or deflection of the cover **609**. In some cases, the intermediate layer **1106** is compressible to allow the first force-sensitive film **1102** to deflect with respect to the second force-sensitive film **1104**. In other cases, the intermediate layer **1106** may not be compressible and the first force-sensitive film **1102** deflects in a predictable manner with respect to the second force-sensitive film **1104**. While FIG. **11** depicts an example force sensor **1100** having two force-sensitive films, alternative embodiments may include only a single force-sensitive film or, alternatively, include more than two force-sensitive films.

In general, a transparent force-sensitive film may include a compliant material that exhibits an electrical property that is variable in response to deformation or deflection of the film. The transparent force-sensitive film may be formed from a piezoelectric, piezo-resistive, resistive, or other strain-sensitive materials. Transparent resistive films can be formed by coating a substrate with a transparent conductive material. Potential transparent conductive materials include, for example, polyethyleneioxythiophene (PEDOT), indium tin oxide (ITO), carbon nanotubes, graphene, silver nanowire, other metallic nanowires, and the like. Potential substrate materials include, for example, glass or transparent polymers like polyethylene terephthalate (PET) or cycloolefin polymer (COP). Typically, when a piezo-resistive or resistive film is strained, the resistance of the film changes as a function of the strain. The resistance can be measured with an electrical circuit. In this way, a transparent piezo-resistive or resistive film can be used in a similar fashion as a strain gauge.

If transparency is not required, then other film materials may be used, including, for example, Constantan and Karma alloys for the conductive film and a polyimide may be used as a substrate. Nontransparent applications include force sensing on track pads or the back of display elements. In general, transparent and non-transparent force-sensitive films may be referred to herein as "force-sensitive films" or simply "films."

In some embodiments, the force-sensitive film is patterned into an array of lines, pixels, or other geometric elements herein referred to as film elements. The regions of the force-sensitive film or the film elements may also be connected to sense circuitry using electrically conductive traces or electrodes. FIG. **12** depicts a cross-sectional view a device having a strain-based force sensor **1200** formed from one or more strain pixel elements **1202** and **1204** separated by intermediate layer **1206**. Each of the pixel elements **1202**, **1204** may be separated by a gap **1210**. In the present example, each pixel element **1202**, **1204** may exhibit a measurable change in an electrical property in response to a force being applied to the device. By way of example, as a force is applied to a surface **1211** on the cover **609**, one or more of the pixel elements **1202**, **1204** is deflected or deformed. Sense circuitry, which is in electrical communication with the one or more pixel elements **1202**, **1204**, may be configured to detect and measure the change in the electrical property of the film due to the deflection. Based on the measured electrical property of the pixel elements **1202**, **1204**, an estimated amount of force can be computed. In some cases, the estimated force may represent the magnitude of a touch on the surface **1211** of the device, and be used as an input to a graphical user interface or other element of the device. Additionally, in some embodiments, the relative strain of the individual pixel elements may be compared to estimate a location of the touch. While FIG. **12** depicts an example force sensor **1200** having two layers of pixel elements, alternative embodiments may include only a single layer of pixel elements or, alternatively, include more than two layers of pixel elements.

The pixel elements **1202**, **1204** may be specifically configured to detect strain along one or more directions. In some

cases, each pixel element **1202**, **1204** includes an array of traces generally oriented along one direction. This configuration may be referred to as a piezo-resistive or resistive strain gauge configuration. In general, in this configuration the force-sensitive-film is a material whose resistance changes in response to strain. The change in resistance may be due to a change in the geometry resulting from the applied strain. For example, an increase in length combined with decrease in cross-sectional area may occur in accordance with Poisson's effect. The change in resistance may also be due to a change in the inherent resistivity of the material due to the applied strain. For example, the applied strain may make it easier or harder for electrons to transition through the material. The overall effect is for the total resistance to change with strain due to the applied force.

Further, in a piezo-resistive or resistive strain gauge configuration, each pixel may be formed from a pattern of the force-sensitive-film, aligned to respond to strain along a particular axis. For example, if strain along an x-axis is to be measured, the pixel should have a majority of its trace length aligned with the x-axis. By way of example, FIG. **13**A depicts a pixel element **1302** having traces that are generally oriented along the x-axis and may be configured to produce a strain response that is substantially isolated to strain in the x-direction. Similarly, FIG. **13**B depicts a pixel element **1304** having traces that are generally oriented along the y-axis and may be configured to produce a strain response that is substantially isolated to strain in the y-direction.

In some embodiments, the force-sensitive film may be formed from a solid sheet of material and is in electrical communication with a pattern of electrodes disposed on one or more surfaces of the force-sensitive film. The electrodes may be used, for example, to electrically connect a region of the solid sheet of material to sense circuitry. This configuration may be referred to as a piezo-strain configuration. In this configuration, the force-sensitive film may generate a charge when strained. The force-sensitive film may also generate different amounts of charge depending on the degree of the strain. In some cases, the overall total charge is a superposition of the charge generated due to strain along various axes.

As mentioned previously, a force sensor may be combined with a touch sensor that is configured to detect and measure the location of a touch on the surface of the device. FIG. **14**A depicts a simplified schematic representation of an example mutual capacitance touch sensor. As shown in FIG. **14**A, a touch sensor **1430** may be formed by an array of nodes **1402** formed at the intersection of an array of drive lines **1404** and sense lines **1406**. In this example, stray capacitance C_{stray} may be present at each node **1402** (although FIG. **14**A depicts only one C_{stray} for one column for purposes of simplifying the figure). In the example of FIG. **14**A, AC stimuli V_{stim} **1414**, V_{stim} **1415** and V_{stim} **1417** can be at different frequencies and phases. Each stimulation signal on a row can cause a charge $Q_{sig}=C_{sig}\times V_{stim}$ to be injected into the columns through the mutual capacitance present at the affected nodes **1402**. A change in the injected charge (Q_{sig_sense}) can be detected when a finger, palm or other object is present at one or more of the affected nodes **1402**. V_{stim} signals **1414**, **1415** and **1417** can include one or more bursts of sine waves. Note that although FIG. **14**A illustrates rows **1404** and columns **1406** as being substantially perpendicular, they need not be aligned, as described above. Each column **1406** may be operatively coupled to a receive channel of a charge-monitoring circuit.

FIG. **14**B depicts a side view of an exemplary node in a steady-state (no touch) condition according to examples of

the disclosure. In FIG. **14**B, electric field lines **1408** between a column **1406** and a row **1404** separated by dielectric **1410** is shown at node **1402**.

FIG. **14**C depicts a side view of an exemplary pixel in a dynamic (touch) condition. An object such as finger **1412** can be placed near node **1402**. Finger **1412** can be a low-impedance object at signal frequencies, and can have an AC capacitance C_{finger} from the column trace **1406** to the body. The body can have a self-capacitance to ground C_{body} of about 200 pF, where C_{body} can be much larger than C_{finger}. If finger **1412** blocks some electric field lines **1408** between row and column electrodes (those fringing fields that exit the dielectric **1410** and pass through the air above the row electrode), those electric field lines can be shunted to ground through the capacitance path inherent in the finger and the body, and as a result, the steady state signal capacitance C_{sig} can be reduced by DC_{sig}. In other words, the combined body and finger capacitance can act to reduce C_{sig} by an amount DC_{sig} (which can also be referred to herein as C_{sig_sense}), and can act as a shunt or dynamic return path to ground, blocking some of the electric field lines as resulting in a reduced net signal capacitance. The signal capacitance at the pixel becomes C_{sig}-DC_{sig}, where DC_{sig} represents the dynamic (touch) component. Note that C_{sig}-DC_{sig} may always be nonzero due to the inability of a finger, palm or other object to block all electric fields, especially those electric fields that remain entirely within the dielectric material. In addition, it should be understood that as finger **1412** is pushed harder or more completely onto the touch sensor, finger **1412** can tend to flatten, blocking more and more of the electric fields lines **1408**, and thus DC_{sig} may be variable and representative of how completely finger **1412** is pushing down on the panel (i.e., a range from "no-touch" to "full-touch").

Additionally or alternatively, the touch sensor may be formed from an array of self-capacitive pixels or electrodes. FIG. **15**A depicts an example touch sensor circuit corresponding to a self-capacitance touch pixel electrode and sensing circuit. Touch sensor circuit **1509** can have a touch pixel electrode **1502** with an inherent self-capacitance to ground associated with it, and also an additional self-capacitance to ground that can be formed when an object, such as finger **1512**, is in proximity to or touching the touch pixel electrode **1502**. The total self-capacitance to ground of touch pixel electrode **1502** can be illustrated as capacitance **1504**. Touch pixel electrode **1502** can be coupled to sensing circuit **1514**. Sensing circuit **1514** can include an operational amplifier **1508**, feedback resistor **1516**, feedback capacitor **1510** and an input voltage source **1506**, although other configurations can be employed. For example, feedback resistor **1516** can be replaced by a switch capacitor resistor. Touch pixel electrode **1502** can be coupled to the inverting input of operational amplifier **1508**. An AC input voltage source **1506** can be coupled to the non-inverting input of operational amplifier **1508**. Touch sensor circuit **1509** can be configured to sense changes in the total self-capacitance **1504** of touch pixel electrode **1502** induced by finger **1512** either touching or in proximity to the touch sensor panel. Output **1520** can be used by a processor to determine a presence of a proximity or touch event, or the output can be inputted into a discreet logic network to determine the presence of a touch or proximity event.

FIG. **15**B depicts an example self-capacitance touch sensor **1530**. Touch sensor **1530** can include a plurality of touch pixel electrodes **1502** disposed on a surface and coupled to sense channels in a touch controller, can be driven by stimulation signals from the sense channels through drive/sense interface **1525**, and can be sensed by the sense

channels through the drive/sense interface **1525** as well. After touch controller has determined an amount of touch detected at each touch pixel electrode **1502**, the pattern of touch pixels in the touch screen panel at which touch occurred can be thought of as an "image" of touch (e.g., a pattern of fingers touching the touch screen). The arrangement of the touch pixel electrodes **1502** in FIG. **15**B is provided as one example; however, the arrangement and/or the geometry of the touch pixel electrodes may vary depending on the embodiment.

As previously mentioned, a force sensor may be implemented alone or in combination with another type of touch sensor to sense both touch force and touch location, which may enable more sophisticated user touch input than using touch location alone. For example, a user may manipulate a computer-generated object on a display using a first type of interaction using a relatively light touch force at a given touch location. The user may also interact with the object using a second type of interaction by using a relatively heavy or sharper touch force at the given location. As one specific example, a user may manipulate or move a computer-generated object, such as a window, using a relatively light touch force. Additionally or alternatively, the user may also select or invoke a command associated with the window using a relatively heavy or sharper touch force. In some cases, multiple types of interactions may be associated with multiple amounts of touch force.

Additionally, it may be advantageous for the user to be able to provide an analog input using a varying amount of force. A variable, non-binary input may be useful for selecting within a range of input values. The amount of force may, in some cases, be used to accelerate a scrolling operation, a zooming operation, or other graphical user interface operation. It may also be advantageous to use the touch force in a multi-touch sensing environment. In one example, the force of a touch may be used to interpret a complex user input performed using multiple touches, each touch having a different magnitude or degree of force. As a specific but non-limiting example, touch and force may be used in a multi-touch application that allows the user to play a varying tone or simple musical instrument using the surface of the device. In such a housing, the force of each touch may be used to interpret a user's interaction with the buttons or keys of a virtual instrument. Similarly, the force of multiple touches can be used to interpret a user's multiple touches in a game application that may accept multiple non-binary inputs at different locations.

4. Sensor or Biosensor Module

As described above with respect to FIG. **2**, a wearable electronic device may include one or more sensors that can be used to calculate a health metric or other health-related information. For the purposes of the following description of the biosensor module, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100** including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a wearable electronic device may function as a wearable health assistant that provides health-related information (whether real-time or not) to the user, authorized third parties, and/or an associated monitoring device. The wearable health assistant may be configured to provide health-related information or data such as, but not limited to, heart rate data, blood pressure data, temperature data, blood oxygen saturation level data, diet/nutrition information, medical reminders, health-related tips or information, or other health-related data. The associated monitoring device may be, for example, a tablet computing device, phone, personal digital assistant, computer, and the like.

In accordance with some embodiments, the electronic device can be configured in the form of a wearable electronic device that is configured or configurable to provide a wide range of functionality. As described above with respect to FIG. **2**, the wearable electronic device **100** may include a processing units **102** coupled with or in communication with a memory **104**, one or more communications channels **108**, output devices such as a display **120** and speaker **122**, one or more input components **106**, and other modules or components. An example wearable electronic device **100** may be configured to provide or calculate information regarding time, health information, biostatistics, and/or status to externally connected or communicating devices and/or software executing on such devices. The device **100** may also be configured to send and receive messages, video, operating commands, and other communications.

With reference to FIG. **16**, an example device **100** may include various sensors for measuring and collecting data that may be used to calculate a health metric or other health-related information. As one example, the wearable communication device can include an array of light sources **1611**-**1613** and a detector **1614** that are configured to function as an optical sensor or sensors. In one example, an optical sensor or sensors may implemented as a pairing of one or more light sources **1611**-**1613** and the detector **1614**. In one example implementation, the detector **1614** is configured to collect light and convert the collected light into an electrical sensor signal that corresponds to the amount of light incident on a surface of the detector **1614**. In one embodiment, the detector may be a photodetector, such as a photodiode. In other embodiments, the detector **1614** may include a phototube, photosensor, or other light-sensitive device.

In some cases, the one or more optical sensors may operate as a photoplethysmography (PPG) sensor or sensors. In some instances, a PPG sensor is configured to measure light and produce a sensor signal that can be used to estimate changes in the volume of a part of a user's body. In general, as light from the one or more light sources passes through the user's skin and into the underlying tissue, some light is reflected, some is scattered, and some light is absorbed, depending on what the light encounters. The light that is received by the detector **1614** may be used to generate a sensor signal, which may be used to estimate or compute a health metric or other physiological phenomena.

The light sources may operate at the same light wavelength range, or the light sources can operate at different light wavelength ranges. As one example, with two light sources, one light source may transmit light in the visible wavelength range while the other light source can emit light in the infrared wavelength range. In some cases, a modulation pattern or sequence may be used to turn the light sources on and off and sample or sense the reflected light. With reference to FIG. **16**, the first light source **1611** may include, for example, a green LED, which may be adapted for detecting blood perfusion in the body of the wearer. The second light source **1612** may include, for example, an infrared LED, which may be adapted to detect changes in water content or other properties of the body. The third **1613** light source may be a similar type or different types of LED element, depending on the sensing configuration.

The optical (e.g., PPG) sensor or sensors may be used to compute various health metrics, including, without limitation, a heart rate, a respiration rate, blood oxygenation level,

a blood volume estimate, blood pressure, or a combination thereof. In some instances, blood may absorb light more than surrounding tissue, so less reflected light will be sensed by the detector of the PPG sensor when more blood is present. The user's blood volume increases and decreases with each heartbeat. Thus, in some cases, a PPG sensor may be configured to detect changes in blood volume based on the reflected light, and one or more physiological parameters of the user may be determined by analyzing the reflected light. Example physiological parameters include, but are not limited to, heart rate, respiration rate, blood hydration, oxygen saturation, blood pressure, perfusion, and others.

While FIG. **16** depicts one example embodiment, the number of light sources and/or detectors may vary in different embodiments. For example, another embodiment may use more than one detector. Another embodiment may also use fewer or more light sources than are depicted in the example of FIG. **16**. In particular, in the example depicted in FIG. **16**, the detector **1614** is shared between multiple light sources **1611-1613**. In one alternative embodiment, two detectors may be paired with two corresponding light sources to form two optical sensors. The two sensors (light source/detector pairs) may be operated in tandem and used to improve the reliability of the sensing operation. For example, output of the two detectors may be used to detect a pulse wave of fluid (e.g., blood) as it passes beneath the respective detectors. Having two sensor readings taken at different locations along the pulse wave may allow the device to compensate for noise created by, for example, movement of the user, stray light, and other effects.

In some implementation, one or more of the light sources **1611-1613** and the detector **1614** may also be used for optical data transfer with a base or other device. For example, the detector **1614** may be configured to detect light produced by an external mating device, which may be interpreted or translated into a digital signal. Similarly, one or more of the light sources **1611-1613** may be configured to transmit light that may be interpreted or translated into a digital signal by an external device.

Returning to FIG. **16**, the device **100** may also include one or more electrodes to measure electrical properties of the user's body. In this example, a first electrode **1601** and second electrode **1602** are disposed on the rear face of the device **100**. The first **1601** and second **1602** electrodes may be configured to make contact with the skin of the user's wrist when the device is being worn. As shown in FIG. **16**, a third electrode **1603** and fourth electrode **1604** may be disposed along a periphery of the device body **610**. In the configuration of FIG. **16**, the third **1603** and fourth **1604** electrodes are configured to come into contact with the skin of the user's other hand (that is not wearing the device **100**). For example, the third **1603** and fourth **1604** electrodes may be contacted when the user pinches the device **100** between two digits (e.g., a forefinger and thumb).

FIG. **16** depicts one example arrangement of electrodes. However, in other embodiments, one or more of the electrodes may be placed in locations that are different than the configuration of FIG. **16**. For example, one or more electrodes may be placed on a top surface or other surface of the device **100**. Additionally, fewer electrodes or more electrodes may be used to contact the user's skin, depending on the configuration.

Using the electrodes of the device, various electrical measurements may be taken, which may be used to compute a health metric or other health-related information. By way of example, the electrodes may be used to detect electrical activity of the user's body. In some cases, the electrodes may be configured to detect electrical activity produced by the heart of the user to measure heart function or produce an electrocardiograph (ECG). As another example, the electrodes of the device may be used to detect and measure conductance of the body. In some cases, the measured conductance may be used to compute a galvanic skin response (GSR), which may be indicative of the user's emotional state or other physiological condition. By way of further example, the electrodes may also be configured to measure other health characteristics, including, for example, a body fat estimate, body or blood hydration, and blood pressure.

In some embodiments, the optical sensors and electrodes discussed above with respect to FIG. **16** may be operatively coupled to sensing circuitry and the processing units **102** to define a health monitoring system. In this capacity, the processing units **102** may be any suitable type of processing device. In one embodiment, the processing units **102** include a digital signal processor. The processing units **102** may receive signals from the optical sensor(s) and/or electrodes and process the signals to correlate the signal values with a physiological parameter of the user. As one example, the processing units **102** can apply one or more demodulation operations to the signals received from the optical sensor. Additionally, the processing units **102** may control the modulation (i.e., turning on and off) of the light sources according to a given modulation pattern or sequence. The processing units **102** may also be used to calculate one or more biometrics or other heath related information.

In some implementations, the wearable electronic device may also receive sensor data or output from an external device. For example, an external mobile device having a global positioning system (GPS) may relay location information to the wearable device, which may be used to calibrate an activity metric, such as a pedometer or distance calculator. Similarly, sensor output of the wearable electronic device may be transmitted to an external device to compute health-related information. For example, output from an accelerometer in the wearable electronic device may be used determine a body position or gesture, which may be relayed to an external device and used to compute health-related information, such as activity level.

In some embodiments, some or all of the biosensors may be integrated into a module that is separate from and attached to the housing **601** of the device **100**. As described above with respect to FIG. **6**, in some embodiments, the biosensors are disposed relative to or attached to a rear cover **608** that is formed from an optically transparent material and is configured to be positioned with the opening of the housing **601**. In some embodiments, the rear cover **608** is disposed completely within the area of the cover so that the two components completely overlap when viewed from above. In some embodiments, the rear cover **608** has an edge that protrudes outwardly from the back surface of the housing **601**. In some embodiments, an edge of the rear cover **608** extends past a flat portion of the back surface of the housing **601**. The rear cover **608** may also have a convex, curved outer contour. The rear cover **608** may have a convex shape that is located within the center and surrounded by the edges of the rear cover **608**. The convex curved area of the rear cover **608** may include one or more windows or apertures that provide operational access to one or more internal components located within the housing. For example, the rear cover **608** may include an array of windows, each window including an aperture or opening for a respective light source **1611-1613** and/or the detector **1614**. In some embodiments, the windows have a curvature

that matches the curvature of the convex curved area of the rear cover **608**. In some embodiments, rear cover **608** includes a chamfered edge and a curved bottom surface, the windows being disposed within the curved surface. In some embodiments, two openings of the rear cover **608** are located along a first axis (e.g., an x-axis) and two openings are located along a second axis (e.g., a y-axis) that is transverse to the first axis.

5. Example Wireless Communications with External Devices

A wearable electronic device may include a functionality for performing wireless communications with an external device. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, the wireless communications are performed in accordance with a Near Field Communications (NFC) protocol. The communication may include an identification protocol and a secured data connection that can be used to identify the user, authorize activity, perform transactions, or conduct other aspects of electronic commerce.

FIG. **17** depicts an example system **1700** including a device **100** that is located proximate to a station **1710**. The station **1710** may include a variety of devices, including, without limitation, a payment kiosk, a vending machine, a security access point, a terminal device, or other similar device. In some cases, the station **1710** is incorporated into a larger system or device. For example, the station **1710** may be incorporated into a security gate of a building or a payment center for a vending system.

As shown in FIG. **17**, the device **100** is a wearable electronic device that may be placed proximate to the station **1710**. In this example, a second device **1720** is carried by a user, and may also be placed proximate to the station **1710**. In some embodiments, the device **100** and/or the second device **1720** includes a radio-frequency identification (RFID) system that is configured to enable one-way or two-way radio-frequency (RF) communications with the station **1710**. The one- or two-way communication may include an identification of the device **100** and the station **1710** to initiate a secured data connection between the two devices. The secured data connection may be used to authorize a transaction between the user and an entity that is associated with the station **1710**.

In some embodiments, the user may initiate a communication with the station **1710** by placing the device **100** near an active region on the station **1710**. In some implementations, the station **1710** is configured to automatically detect the presence of the device **100** and initiate an identification process or routine. The RFID system of the device may include a unique identifier or signature that may be used to authenticate the identity of the user. As previously mentioned, the identification process or routine may be used to establish a secure data connection between the device **100** and the station **1710**. The secure data connection may be used to authorize a purchase or download of data to or from the device **100**. In some cases, the secure data connection may be used to authorize the transfer of funds from a credit card or financial institution in exchange for a product that is associated with the station **1710**. Other transactions or forms of electronic commerce may also be performed using the wireless communication between the device **100** and the station **1710**.

6. Example Wireless Power System

As discussed above, a wearable electronic device may include an internal battery that is rechargeable using an external power source. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

One challenge associated with small devices is that it may be difficult to incorporate an electrical port for coupling the device to an external power source. Because wearable electronic devices have limited space for an external connector, it may be advantageous to electrically couple to a device without a cable or external connector. In at least some embodiments, the wearable electronic device described herein may be configured to operate as a receiver in a wireless power transfer system.

A wireless power transfer system, one example of which is an inductive power transfer system, typically includes a power-transmitting structure to transmit power and a power-receiving structure to receive power. In some examples, a power-receiving electronic device includes or otherwise incorporates an inductive power-receiving element configured to receive wireless power and/or charge one or more internal batteries. Similarly, a charging device may include or otherwise incorporate an indicative power-transmitting element configured to wirelessly transmit power to the power-receiving electronic device. The charging device may be configured as a base or dock on which the power-receiving electronic device rests or to which it physically connects in some embodiments. In other embodiments, the charging device may be proximate the electronic device but not necessarily touching or physically coupled.

In many examples, the battery-powered electronic device may be positioned on an external surface of the power-transmitting device, otherwise referred to as a dock. In these systems, an electromagnetic coil within the dock (e.g., transmit coil) may produce a time-varying electromagnetic flux to induce a current within an electromagnetic coil within the electronic device (e.g., receive coil). In many examples, the transmit coil may transmit power at a selected frequency or band of frequencies. In one example the transmit frequency is substantially fixed, although this is not required. For example, the transmit frequency may be adjusted to improve inductive power transfer efficiency for particular operational conditions. More particularly, a high transmit frequency may be selected if more power is required by the electronic device and a low transmit frequency may be selected if less power is required by the electronic device. In other examples, a transmit coil may produce a static electromagnetic field and may physically move, shift, or otherwise change its position to produce a spatially-varying electromagnetic flux to induce a current within the receive coil.

The electronic device may use the received current to replenish the charge of a rechargeable battery or to provide power to operating components associated with the electronic device. Thus, when the electronic device is positioned on the dock, the dock may wirelessly transmit power at a particular frequency via the transmit coil to the receive coil of the electronic device.

A transmit coil and receive coil may be disposed respectively within housings of the dock and electronic device so as to align along a mutual axis when the electronic device is placed on the dock. If misaligned, the power transfer efficiency between the transmit coil and the receive coil may decrease as misalignment increases. Accordingly, in many

examples, the wireless power transfer system may include one or more alignment assistance features to effect alignment of the transmit and receive coils along the mutual axis.

FIG. **18** depicts a front perspective view of an example wireless power transfer system **1800** in an unmated configuration. The illustrated embodiment shows an inductive power transmitter dock **1802** that is configured to couple to and wirelessly transmit power to an inductive power receiver accessory, in this case device **100**. The wireless power transfer system **1800** may include one or more alignment assistance features to effect alignment of the device **100** with the dock **1802** along a mutual axis. For example, the housings of the dock **1802** and the device **100** may assist with alignment. In one implementation, a portion of the housing of the device **100** may engage and/or interlock with a portion of the housing of the dock **1802** in order to effect the desired alignment. In some embodiments, a bottom portion of the device **100** may be substantially convex and a top surface of the dock **1802** may be substantially concave. In other examples, the interfacing surfaces of the dock **1802** and the device **100** may be substantially flat, or may include one or more additional housing features to assist with effecting mutual alignment.

In some embodiments, one or more actuators in the dock **1802** and/or device **100** can be used to align the transmitter and receiver devices. In yet another example, alignment assistance features, such as protrusions and corresponding indentations in the housings of the transmitter and receiver devices, may be used to align the transmitter and receiver devices. The design or configuration of the interface surfaces, one or more alignment assistance mechanisms, and one or more alignment features can be used individually or in various combinations thereof.

Alignment assistance can also be provided with one or more magnetic field sources. For example, a permanent magnet within the dock **1802** may attract a permanent magnet within the device **100**. In another example, a permanent magnet within the device **100** may be attracted by a magnetic field produced by the dock **1802**. In further examples, multiple alignment assistance features may cooperate to effect alignment of the transmit and receive coils. Power transfer efficiency may also decrease if the power consumption of the electronic device changes (e.g., the electronic device transitions from a trickle charge mode to constant current charge mode) during wireless power transfer.

As discussed previously with respect to FIG. **2**, the device **100** may include a processor coupled with or in communication with a memory, one or more communication interfaces, output devices such as displays and speakers, and one or more input devices such as buttons, dials, microphones, or touch-based interfaces. The communication interface(s) can provide electronic communications between the communications device and any external communication network, device or platform, such as, but not limited to, wireless interfaces, Bluetooth interfaces, Near Field Communication interfaces, infrared interfaces, USB interfaces, Wi-Fi interfaces, TCP/IP interfaces, network communications interfaces, or any conventional communication interfaces. The device **100** may provide information regarding time, health, statuses or externally connected or communicating devices and/or software executing on such devices, messages, video, operating commands, and so forth (and may receive any of the foregoing from an external device), in addition to communications.

In the example depicted in FIG. **18**, the dock **1802** may be connected to an external power source, such as an alternating current power outlet, by power cord **1808**. In other embodiments, the dock **1802** may be battery operated. In still further examples, the dock **1802** may include a power cord **1808** in addition to an internal or external battery. Similarly, although the embodiment is shown with the power cord **1808** coupled to the housing of the dock **1802**, the power cord **1808** may be connected by any suitable means. For example, the power cord **1808** may be removable and may include a connector that is sized to fit within an aperture or receptacle opened within the housing of the dock **1802**.

Although the device **100** is shown in FIG. **18** as larger than the dock **1802**, the depicted scale may not be representative of all embodiments. For example, in some embodiments the dock **1802** may be larger than the device **100**. In still further embodiments the two may be substantially the same size and shape. In other embodiments, the dock **1802** and device **100** may take separate shapes.

FIG. **19** depicts a simplified block diagram of relevant aspects of the device **100** and dock **1802**. It may be appreciated that certain components of both the dock **1802** and device **100** are omitted from the figure for clarity. Likewise, the positions of the elements that are shown are meant to be illustrative rather than necessarily portraying a particular size, shape, scale, position, orientation, or relation to one another, although some embodiments may have elements with one or more of such factors as illustrated.

As described previously with respect to FIG. **2**, the device **100** may include one or more electronic components located within the housing **601**. For clarity, some of the components and modules described or depicted in various embodiments are omitted from the depiction of FIG. **19**. As shown in FIG. **19**, the device **100** may include an internal battery **114** that may be used to provide power to the various internal components of the device **100**. As described previously, the internal battery **114** may be rechargeable by an external power supply. In the present example, the internal battery **114** is operably connected to a receive coil **1869** via power conditioning circuit **1810**.

In the present example, the device **100** includes a receive coil **1869** having one or more windings for inductively coupling with a transmit coil **1832** of the dock **1802**. The receive coil **1869** may receive power wirelessly from the dock **1802** and may pass the received power to a battery **114** within the device **100** via power conditioning circuit **1810**. The power conditioning circuit **1810** may be configured to convert the alternating current received by the receive coil **1869** into direct current power for use by other components of the device. In one example, the processing units **102** may direct the power, via one or more routing circuits, to perform or coordinate one or more functions of the device **100** typically powered by the battery **114**.

As shown in FIG. **19**, the dock **1802** includes a transmit coil **1832** having one or more windings. The transmit coil **1832** may transmit power to the device **100** via electromagnetic induction or magnetic resonance. In many embodiments, the transmit coil **1832** may be shielded with a shield element that may be disposed or formed around portions of the transmit coil **1832**. Similarly, the receive coil **1869** may also include a shield element that may be disposed or formed around a portion of the receive coil **1869**.

As shown in FIG. **19**, the dock **1802** also includes a processor **1834** that may be used to control the operation of or coordinate one or more functions of the dock **1802**. In some embodiments, the dock **1802** may also include one or more sensors **1836** to determine whether the device **100** is present and ready to receive transmitted power from the dock **1802**. For example, the dock **1802** may include an

optical sensor, such as an infrared proximity sensor. When the device **100** is placed on the dock **1802**, the infrared proximity sensor may produce a signal that the processor **1834** uses to determine the presence of the device **100**. The processor **1834** may, optionally, use another method or structure to verify the presence of the electronic device via sensor **1836**. Examples of different sensors that may be suitable to detect or verify the presence of device **100** may include a mass sensor, a mechanical interlock, switch, button or the like, a Hall effect sensor, or other electronic sensor. Continuing the example, after the optical sensor reports that the device **100** may be present, the processor **1834** may activate a communication channel to attempt to communicate with the device **100**.

As illustrated in FIG. **19**, a bottom surface of the housing of the device **100** may partially contact a top surface of the dock housing. In some implementations, the interfacing surfaces of the device **100** and the dock **1802** may be formed with complementary geometries. For example, as depicted in FIG. **19**, the bottom surface of the device **100** is convex and the top surface of the dock **1802** is concave, following the same curvature as the bottom surface of the device **100**. In this manner, the complementary geometries may facilitate alignment of the electronic device and dock for efficient wireless power transfer.

In some embodiments, the dock **1802** and device **100** may include other alignment assistance features. For example the device **100** may include an alignment magnet **1838** which is positioned and oriented to attract a corresponding alignment magnet **1840** within the dock **1802**. In some cases, when the device **100** is positioned proximate the dock **1802**, the alignment magnets **1838**, **1840** may be mutually attracted, thereby affecting alignment of the portable electronic device **100** and the dock **1802** along a mutual axis. In other examples, the dock **1802** may include a ferromagnetic material in place of the alignment magnet **1840**. In these examples, the alignment magnet **1838** may be attracted to the ferromagnetic material. In still further cases, the receive coil **1869** or transmit coil **1832** may produce a static magnetic field that either attracts or repels either or both of the alignment magnets **1838**, **1840**.

As shown in FIG. **19**, the alignment magnets **1838**, **1840** may be positioned within a respective coil **1869**, **1832**. When the alignment magnets **1838**, **1840** are drawn together, the coils **1869**, **1832** may be placed into alignment. Additionally, the complementary geometries of the device **100** and the dock **1802** may further facilitate alignment when the alignment magnets **1838**, **1840** are drawn together.

7. Example Acoustic Module

As described above, the device may include one or more devices for transmitting and receiving acoustic energy. For the purposes of the following description of the acoustic module, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above. As previously discussed, in some embodiments, the device may include a speaker for transmitting acoustic energy and/or a microphone for receiving acoustic energy. For the purposes of the following description, a speaker device and a microphone are referred to generically as an acoustic module, which may be configured to transmit and/or receive acoustic energy depending on the particular implementation.

FIG. **20** depicts a simplified schematic cross-sectional view of a first embodiment of a device having an acoustic module **2006**. The representation depicted in FIG. **20** is not drawn to scale and may omit some elements for clarity. The acoustic module **2006** may represent either a portion of a speaker and/or microphone device described above with respect to the electronic device **100** of FIG. **2**.

As shown in FIG. **20**, an acoustic port **2020** may be formed in the housing **601** of the electronic device. In the present example, the acoustic port **2020** includes first and second orifices **2031**, **2032** that are formed in the housing **601** and acoustically couple the acoustic cavity **2011** of the acoustic module **2006** to the external environment (external to the electronic device). In the present embodiment, the first and second orifices **2031**, **2032** are offset with respect to the opening of the acoustic cavity **2011**. This configuration may help reduce the direct ingress of liquid **2001** into acoustic cavity **2011** of the acoustic module **2006** Also, as shown in FIG. **20** a shield **2021** or umbrella structure that is formed between the orifices **2031**, **2032** blocks the direct ingress of liquid **2001** into the acoustic cavity **2011**. As shown in FIG. **20**, the acoustic module **2006** also includes a screen element **2015** disposed at one end of the acoustic cavity **2011**, which may also prevent the ingress of liquid or other foreign debris into the acoustic cavity **2011**. The acoustic module **2006** also includes a seal **2016** disposed between the housing **601** and the connector element **2012** of the module, which may also be configured to prevent the ingress of water into the device and/or module.

In the present example depicted in FIG. **20**, the acoustic module **2006** may correspond to the speaker **122** described with respect to some embodiments. As shown in FIG. **20**, the acoustic module **2006** includes various components for producing and transmitting sound, including a diaphragm **2010**, a voice coil **2009**, a center magnet **2008**, and side magnets/coils **2007**. These components may cooperate to form a speaker acoustic element. In one implementation, the diaphragm **2010** is configured to produce sound waves or an acoustic signal in response to a stimulus signal in the center magnet **2008**. For example, a modulated stimulus signal in the center magnet **2008** causes movement of the voice coil **2009**, which is coupled to the diaphragm **2010**. Movement of the diaphragm **2010** creates the sound waves, which propagate through the acoustic cavity **2011** of acoustic module **2006** and eventually out the acoustic port **2020** to a region external to the device. In some cases, the acoustic cavity **2011** functions as an acoustical resonator having a shape and size that is configured to amplify and/or dampen sound waves produced by movement of the diaphragm **2010**.

As shown in FIG. **20**, the acoustic module **2006** also includes a yoke **2014**, support **2013**, connector element **2012**, and a cavity wall **2017**. These elements provide the physical support of the speaker elements. Additionally, the connector element **2012** and the cavity wall **2017** together form at least part of the acoustic cavity **2011**. The specific structural configuration of FIG. **20** is not intended to be limiting. For example, in alternative embodiments, the acoustic cavity may be formed from additional components or may be formed from a single component.

The acoustic module **2006** depicted in FIG. **20** is provided as one example of a type of speaker acoustic module. In other alternative implementations, the acoustic module may include different acoustic elements for producing and transmitting sound, including, for example, a vibrating membrane, piezoelectric transducer, vibrating ribbon, or the like. Additionally, in other alternative implementations, the acoustic module may be a microphone acoustic module having one or more elements for converting acoustic energy into an electrical impulse. For example, the acoustic module

may alternatively include a piezoelectric microphone acoustic element for producing a charge in response to acoustic energy or sound.

As previously mentioned, because the acoustic port **2020** connects the acoustic module **2006** to the external environment, there is a possibility that liquid may accumulate or infiltrate the interior of the module. In some cases, the screen element **2015** or other protective features may not prevent all liquid from entering the acoustic cavity **2011** of the module. For example, if the device is subjected to a liquid under pressure or a directed stream of liquid, some liquid ingress may occur. Additionally, naturally occurring moisture in the air may condense and accumulate over time resulting in the presence of liquid within the module. Thus, in some implementations, the acoustic module **2006** may include one or more elements configured to expel water or liquid that accumulates in, for example, the acoustic cavity **2011** of the module. The liquid expulsion process may include modifying the charge on a portion of the wall of the acoustic cavity **2011** to change the surface energy of the wall and/or producing an acoustic pulse using the diaphragm **2010** to help expel liquid from the acoustic cavity **2011**. In some embodiments, the screen **2015** may also have hydrophilic or hydrophobic properties that may facilitate removal of liquid held within the acoustic cavity **2011**.

8. Example Antenna and Cover

As previously described, a wearable electronic device may be configured to communicate wirelessly with various external devices and communication networks. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, as previously discussed with respect to FIG. **2**, the device may include one or more communication channels that are configured to transmit and receive data and/or signals over a wireless communications network or interface. Example wireless interfaces include radio frequency cellular interfaces, Bluetooth interfaces, Wi-Fi interfaces, or any other known communication interface.

In some implementations an antenna may be disposed with respect to the cover (e.g., crystal) of a device to facilitate wireless communications with an external device or communication network. In some cases, it may be advantageous to integrate an antenna into the cover to improve the transmission and reception of wireless signals from the device. In particular, the cover of the device may have dielectric properties that facilitate the transmission of radio frequency signals while also protecting the antenna from physical damage or interference. Additionally, if the antenna is integrated into a perimeter portion of the cover, the visual appearance or clarity of the cover may be minimized. Furthermore, the embodiments described below with respect to FIGS. **21**A-B may be used to integrate an antenna external to the housing, without increasing the thickness of the device body.

FIG. **21**A depicts a perspective exploded view of a cover **2100** and an antenna assembly **2130**. The cover **2100** depicted in FIG. **21**A is viewed from an inner surface **2124** that is configured to attach to or interface with the opening of the housing (described above with respect to FIG. **1**). As shown in FIG. **21**A, a groove **2128** may be formed within the inner surface **2124**. In this example, the groove **2128** is formed around the periphery of the cover **2100**. As mentioned previously, this may be advantageous in minimizing the visual impact of having the antenna assembly **2130** located within the cover **2100**.

As shown in FIG. **21**A the antenna assembly **2130** includes an antenna ring **2134** and a terminal **2140** which may interface with an electrical connector **2150**. In the present embodiment, the groove **2128** formed in the surface of the cover **2100** may be configured to accept the antenna ring **2134**. In particular, the groove **2128** may receive the entire antenna ring **2134** without a portion of the antenna ring **2134** protruding past the inner surface **2124**, when the antenna ring **2134** is installed. In some cases, the groove **2128** is formed to be a clearance or near clearance fit with the diameter of the antenna ring **2134**. Thus, in some cases, the antenna ring **2134** may substantially fill the groove **2128** when the ring is installed. In some cases, the groove **2128** may be configured to retain the antenna ring **2134** due to a slight interference fit or due to a feature formed within either the cover **2100** and/or the antenna assembly **2130**. In the present embodiment, the antenna assembly **2130** may be installed in the cover **2100** and then connected to other electronics via the terminal **2140** and the connector **2150**, which may protrude into an opening in the case or housing.

FIG. **21**B depicts a cross-sectional view of the cover and antenna at the connection point. In particular, FIG. **21**B depicts a detail cross-sectional view of the cover **2100** installed within the housing **601** at a region near the terminal **2140**. In this example, the cover **2100** is attached to a shelf of the housing **601** via a compressible element **2122**. The compressible element **2122** may provide a seal against water or other contaminates and also provide compliance between the cover **2100** and the housing **601**. The compressible element **2122** may be formed from a nitrile or silicone rubber and may also include an adhesive or other bonding agent.

As shown in FIG. **21**B, the antenna ring **2134** is disposed entirely within the groove **2128**. In this case, the antenna ring **2134** does not protrude past the inner surface **2124**. The antenna ring **2134** is electrically connected to the terminal **2140**, which protrudes into an opening in the housing **601**. As shown in FIG. **21**B, the terminal **2140** includes conductive pads **2142** for electrically connecting to the antenna ring **2134**. In this example, spring clips **2152** are configured to mechanically and electrically connect to the conductive pads **2142** on the terminal **2140**. One advantage to the configuration depicted in FIG. **21**B is that the antenna assembly **2130** may be installed in the cover **2100** before the cover **2100** is installed in the housing **601**. The terminal **2140** and connector **2150** facilitate a blind connection that may assist electrical connection as the cover **2100** is installed. Additionally, the configuration depicted in FIG. **21**B may allow for some movement between the cover **2100** and the housing **601** without disturbing the electrical connection with the antenna ring **2134**.

9. Example Haptic Module

As described above, the device may include one or more haptic modules for providing haptic feedback to the user. The embodiments described herein may relate to or take the form of durable and thin haptic feedback elements suitable to provide a perceivable single pulse haptic feedback. In general, a haptic device may be configured to produce a mechanical movement or vibration that may be transmitted through the housing and/or other component of the device. In some cases, the movement or vibration may be transmitted to the skin of the user and perceived as a stimulus or haptic feedback by the user. In some implementations, the haptic feedback may be coupled to one or more device

outputs to alert the user of an event or activity. For example, a haptic output may be produced in combination with an audio output produced by the speaker, and/or a visual output produced using the display.

The space constraints associated with a small wrist-worn device may present unique challenges to integrating a haptic mechanism into wearable electronics. In particular, a haptic mechanism may use a moving mass used to create the movement or vibration of the haptic output. The larger the mass that is moved, the easier it may be to create a perceivable stimulus using the haptic mechanism. However, a large moving mass and the supporting mechanism may be difficult to integrate into the compact space of, for example, the housing of a wearable electronic wristwatch.

Thus, the haptic module implemented in some embodiments may be configured to maximize the mechanical energy that is produced in a very compact form factor. FIGS. **22**A-B depict one example haptic mechanism that may be particularly well suited for use in a wearable electronic device. While the embodiment described with respect to FIGS. **22**A-B is provided as one example, the haptic module is not limited to this particular configuration.

FIG. **22**A depicts a three-quarters perspective view of a haptic device **112**, with a top, front and left sidewall of the housing **2220** removed to expose internal components. FIG. **22**B depicts a cross-sectional perspective view of the haptic device **112** cut in half to expose the internal components. In this example, a coil **2200** is used to induce movement of a frame **2260**, which houses a central magnet array **2210**. As shown in FIGS. **22**A-B, the movement of the frame **2260** is guided by a shaft **2250** that is fixed with respect to a housing **2220**.

In the present example, the coil **2200** may be energized by transmitting a current (e.g., from the battery) along a length of a wire that forms the coil **2200**. A direction of the current along the wire of the coil **2200** determines a direction of a magnetic field that emanates from the coil **2200**. In turn, the direction of the magnetic field determines a direction of movement of the frame **2260** housing the central magnet array **2210**. One or more springs may bias the frame **2260** towards the middle region of the travel. In this example, the frame **2260** and central magnet array **2210**, through operation of the coil **2200**, function as a moving mass, which generates a tap or vibration. The output of the haptic device **112**, created by the moving mass of the frame **2260** and central magnet array **2210**, may be perceived as a haptic feedback or stimulus to the user wearing the device.

For example, when the coil **2200** is energized, the coil **2200** may generate a magnetic field. The opposing polarities of the magnets in the magnet array **2210** generates a radial magnetic field that interacts with the magnetic field of the coil **2200**. The Lorentz force resulting from the interaction of the magnetic fields causes the frame **2260** to move along the shaft **2250** in a first direction. Reversing current flow through the coil **2200** reverses the Lorentz force. As a result, the magnetic field or force on the central magnet array **2210** is also reversed and the frame **2260** may move in a second direction. Thus, frame **2260** may move in both directions along the shaft **2250**, depending on the direction of current flow through the coil **2200**.

As shown in FIG. **22**A, the coil **2200** encircles the central magnet array **2210**, which is disposed near the center of the frame **2260**. As previously described, the coil **2200** may be energized by transmitting a current along the length of the wire forming the coil **2200**, and the direction of the current flow determines the direction of the magnetic flux emanating from the coil **2200** in response to the current. Passing an

alternating current through the coil **2200** may cause the central magnet array **2210** (and frame **2260**) to move back and forth along a shaft **2250**. In order to prevent the central magnet array **2210** from being attracted to the shaft **2250**, which could increase friction between the two and thereby increase the force necessary to move the central magnet array **2210** and frame **2260**, the shaft **2250** may be formed from a non-ferrous material such as tungsten, titanium, stainless steel, or the like.

As depicted in FIGS. **22**A-B, the coil **2200** is positioned within a frame **2260** that holds the central magnet array **2210**, but is not affixed to the coil **2200**. Rather, an air gap separates the coil **2200** from the central magnet array **2210** and the frame **2260** is free to move with respect to the coil **2200**, which is generally stationary. Further, the frame **2260** generally moves with the central magnet array **2210**. As illustrated in FIGS. **22**A-B, the frame **2260** may have an aperture formed therein of sufficient size to contain the coil **2200**. Even when the frame and central magnet array are maximally displaced within the housing **2220** (e.g., to one end or the other of the shaft **2250**), the coil **2200** does not contact any portion of the frame **2260**. It should be appreciated that the coil **2200** remains stationary in the housing **2220** while the frame **2260** and central magnet array **2210** move, although in other embodiments the coil **2200** may move instead of, or in addition to, the frame and/or central magnet array. However, by keeping the coil **2200** stationary, it may be easier to provide interconnections for the coil, such as between the coil and the flex, and therefore reduce the complexity of manufacture.

As shown in FIGS. **22**A-B, the central magnet array **2210** may be formed from at least two magnets **2211**, **2212** of opposing polarities. A center interface **2270** may be formed from a ferrous or non-ferrous material, depending on the embodiment. A ferrous material for the center interface **2270** may enhance the overall magnetic field generated by the central magnet array **2210**, while a non-ferrous material may provide at least a portion of a return path for magnetic flux and thus assist in localizing the flux within the housing **2220**. In some embodiments, the magnets **2211**, **2212** are formed from neodymium while the frame is tungsten. This combination may provide a strong magnetic field and a dense mass, thereby yielding a high weight per volume structure that may be used as the moving part of the haptic device **112**.

10. Example Crown Module

As described above, the device may include a crown that may be used to accept user input to the device. For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2**-**7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

In some embodiments, a crown may be used to accept rotary input from the user, which may be used to control aspects of the device. The crown may be knurled or otherwise textured to improve grip with the user's finger and/or thumb. In some embodiments, a crown may be turned by the user to scroll a display or select from a range of values. In other embodiments, the crown may be rotated to move a cursor or other type of selection mechanism from a first displayed location to a second displayed location in order to select an icon or move the selection mechanism between various icons that are output on the display. In a time keeping application, the crown may also be used to adjust the position of watch hands or index digits displayed on the display of the device. The crown may also be used to control

the volume of a speaker, the brightness of the display screen, or control other hardware settings.

In some embodiments, the crown may also be configured to accept linear, as well as rotary, input. For example, the crown may be configured to translate along an axis when pressed or pulled by the user. In some cases, the linear actuation may be used as additional user input. The actuation may provide a binary output (actuated/not actuated) or may also provide a non-binary output that corresponds to the amount of translation along the axis of motion. In some instances, the linear input to the crown may be combined with the rotary input to control an aspect of the device.

The embodiments described herein may be used for at least a portion of the crown module integrated into a wearable electronic device. The embodiments are provided as examples and may not include all of the components or elements used in a particular implementation. Additionally, the crown module is not intended to be limited to the specific examples described below and may vary in some aspects depending on the implementation.

In some embodiments, an optical encoder may be used to detect the rotational motion of the crown. More specifically, the example provided below with respect to FIG. 23 may use an optical encoder to detect rotational movement, rotational direction and/or rotational speed of a component of the electronic device. Once the rotational movement, rotational direction and/or rotational speed have been determined, this information may be used to output or change information and images that are presented on a display or user interface of the electronic device.

Integrating an optical encoder into the space constraints of a typical wearable electronic device may be particularly challenging. Specifically, some traditional encoder configurations may be too large or delicate for use in a portable electronic device. The optical encoder described below may provide certain advantages over some traditional encoder configurations and may be particularly well suited for use with a crown module of a wearable electronic device.

As shown in the example embodiment of FIG. **23**, the optical encoder of the present disclosure includes a light source **2370**, a photodiode array **2380**, and a shaft **2360**. However, unlike typical optical encoders, the optical encoder of the present disclosure utilizes an encoding pattern disposed directly on the shaft **2360**. For example, the encoding pattern includes a number of light and dark markings or stripes that are axially disposed along the shaft **2360**. Each stripe or combination of stripes on the shaft **2360** may be used to identify a position of the shaft **2360**. For example, as light is emitted from the light source **2370** and reflected off of the shaft **2360** into the photodiode array **2380**, a position, rotation, rotation direction and rotation speed of the shaft **2360** may be determined. Once the rotation direction and speed are determined, this information may be used to output or change information or images that are presented on the display or user interface of the electronic device.

In other embodiments, the shape or form of the shaft of the encoder may be used to determine a position, rotation, rotation direction and rotation speed of the shaft. For example, the shaft may be fluted or have a number of channels that cause the light to be reflected in a number of different directions. Accordingly, a diffractive pattern may be used to determine the rotation, rotation direction and rotation speed of the shaft.

FIG. **23** illustrates a simplified depiction of the device **100** and crown module **642** in accordance with some embodiments. As shown in FIG. **23**, the crown module **642** may be integrated with the housing **601** of the device **100** and may be formed from a dial **2340** disposed at the end of a shaft **2360**. In the present embodiment, the crown module **642** also forms part of the optical encoder. As discussed above, the crown module **642** includes an optical encoder that includes a shaft **2360**, a light source **2370**, and a photodiode array **2380**. Although a photodiode array is specifically mentioned, embodiments disclosed herein may use various types of sensors that are arranged in various configurations for detecting the movement described herein. For example, the movement of the shaft **2360** may be detected by an image sensor, a light sensor such as a CMOS light sensor or imager, a photovoltaic cell or system, photo resistive component, a laser scanner and the like.

The optical encoder may produce an encoder output that is used to determine positional data of the crown module **642**. In particular, the optical encoder may produce an output that is used to detect that movement of the dial **2340** including the direction of the movement, speed of the movement and so on. The movement may be rotational movement, translational movement, angular movement, and so on. The optical encoder may also be used to detect the degree of the change of rotation of the dial **2340** and/or the angle of rotation of the dial **2340** as well as the speed and the direction of the rotation of the dial **2340**.

The signals or output of the optical encoder may be used to control various aspects of other components or modules of the device. For example, continuing with the time keeping application example discussed above, the dial **2340** may be rotated in a clockwise manner in order to advance the displayed time forward. In one implementation, the optical encoder may be used to detect the rotational movement of the dial **2340**, the direction of the movement, and the speed at which the dial **2340** is being rotated. Using the output from the optical encoder, the displayed hands of a time keeping application may rotate or otherwise move in accordance with the user-provided rotational input.

Referring back to FIG. **23**, the crown module **642** may be formed from dial **2340** that is coupled to the shaft **2360**. In some cases, the shaft **2360** and dial **2340** may be formed as a single piece. As the shaft **2360** is coupled to, or is otherwise a part of the dial **2340**, as the dial **2340** rotates or moves in a particular direction and at a particular speed, the shaft **2360** also rotates or moves in the same direction and with the same speed.

As shown in FIG. **23**, the shaft **2360** of the optical encoder includes an encoding pattern **2365**. As discussed above, the encoding pattern **2365** may be used to determine positional information about the shaft **2360** including rotational movement, angular displacement and movement speed. As shown in FIG. **23**, the encoding pattern **2365** may include a plurality of light and dark stripes.

Although light stripes and dark stripes are specifically mentioned and shown, the encoding pattern **2365** may consist of various types of stripes having various shades or colors that provide surface contrasts. For example, the encoding pattern **2365** may include a stripe or marking that has a high reflective surface and another stripe that has a low reflective surface regardless of the color or shading of the stripes or markings. In another embodiment, a first stripe of the encoding pattern **2365** may cause specular reflection while a second stripe of the encoding pattern **2365** may cause diffuse reflection. When the reflected light is received by the photodiode array **2380**, a determination may be made as to the position and movement of the shaft such as described below. In embodiments where a holographic or diffractive pattern is used, the light from the light source **2370** may diffract from the shaft **2360**. Based on the

diffracted light, the photodiode array **2380** may determine the position, movement and direction of movement of the shaft **2360**.

In some embodiments, the stripes of the encoding pattern **2365** extend axially along the shaft **2360**. The stripes may extend along the entire length of the shaft **2360** or partially along a length of the shaft **2360**. In addition, the encoding pattern **2365** may also be disposed around the entire circumference of the shaft **2360**. In other embodiments, the encoding pattern **2365** may include a radial component. In yet other embodiments, the encoding pattern **2365** may have both a radial component and an axial component.

In some embodiments, the crown module may also include a tactile switch for accepting translational input from the user. FIGS. **24**A-B depict another example of a crown module **642***a* having a tactile switch assembly **2410**. As shown in FIG. **24**A, the tactile switch assembly **2410** may include a dial **2448** (or button), a coupling **2418**, a shear plate **2456**, and a tactile switch **2414**.

In the embodiment depicted in FIGS. **24**A-B, the dial **2448** is translatable and/or rotatable relative to the housing. The ability of the dial **2448** to translate and rotate relative to the housing allows a user to provide a rotational force and/or translating force to the tactile switch assembly. In particular, the dial **2448** of the present example may be operably coupled to or form part of an optical encoder, in accordance with the example described above with respect to FIG. **23**.

In the present example, the dial **2448** includes an outer surface **2432** that is configured to receive a rotary or rotational user input and a stem **2450** that extends from an interior surface **2434** of the dial **2448**. The stem **2450** may define a coupling aperture that extends longitudinally along a length or a portion of a length of the stem **2450**. In the depicted example, the stem **2450** may be hollow or partially hollow.

In the example depicted in FIGS. **24**A-B, the coupling **2418** may be a linkage, such as a shaft, that couples the dial **2448** to the tactile switch **2414**. The coupling **2418** may be integrally formed with the dial **2448** or may be a separate component operably connected thereto. For example, the stem **2450** of the dial **2448** may form the coupling member that is integrally formed with the dial **2448**. The coupling **2418** may be made of a conductive material, such as one or more metals or metal alloys. Due to the conductive characteristics, the coupling **2418** may further act to electrically couple the dial **2448** to the tactile switch **2414** and shear plate **2456**. In the example depicted in FIGS. **24**A-B, the shear plate **2456** is positioned between the coupling **2418** and the tactile switch **2414**. In some embodiments, the shear plate **2456** may prevent or reduce shearing forces from the coupling from being transmitted to the tactile switch. The shear plate **2456** also allows transfer of linear force input from the dial **2448** to the switch **2414**.

The configuration depicted in FIGS. **24**A-B may be used to accept both rotational and translational input from the user. For example, if a user provides a rotational force to the dial **2448**, the coupling **2418** and dial **2448** may rotate in the direction of the force. The coupling **2418** may be attached to or integrated with one or more sensors that are configured to detect rotational movement. For example the coupling **2418** may be integrated with an optical encoder, similar to the example described above with respect to FIG. **23**. Additionally, if a user provides a translational force to the dial **2448**, the force may be transmitted through the dial **2448** and coupling **2418** to actuate the switch **2414**. In some cases, the switch **2414** includes a metal dome switch that is configured to provide a tactile feedback when actuated. In some cases, the actuation of a dome switch may be perceived by the user as a click or release as the switch **2414** is actuated. Once the force has been removed from the dial **2448**, the dome switch resiliently returns to its original position, providing a biasing force against the coupling **2418** to return both the dial **2448** and the coupling **2418** to their original positions. In some embodiments, the tactile switch **2414** may include a separate biasing element, such as a spring, that exerts a force (either directly or indirectly via the shear plate) against the coupling. FIG. **24**A depicts the tactile switch assembly **2410** when there is no force applied (un-actuated). FIG. **24**B depicts the tactile switch assembly **2410** when there is a translational force applied to the dial **2448** (actuated).

11. Example Band Attachment Mechanism

For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above.

As described above, a wearable electronic device may include a band that is attached to a device body having one or more receiving features. In particular, the housing may include or form a receiving feature that facilitates an interchange or replacement of different bands that are used to secure the device to the wrist of the user. By replacing or interchanging bands the device may be adapted for multiple uses ranging from sporting activities to professional or social activities.

In some embodiments, the receiving features are configured to be operated without the use of special tools or fixtures. For example, the bands may be interchanged by hand or with the help of a simple tool, such as a pointed object. Additionally or alternatively, a tool or other component, such as a component of the device to which the attachment system is coupled, may be configured to actuate a button or other component of the attachment system to secure and/or release the band from the device. In one embodiment, the lug portion of a band may be configured to be inserted into an opening or channel portion of the receiving feature. Once the lug of the band has been inserted into the opening, the lug may slide within the opening of the device until the band is secured or otherwise coupled to the device. The coupling between the band and the receiving feature may provide a secure attachment of the band to the housing or device body. Just as the band is configured to slide into the channel of the receiving feature, the lug may also slide out of the channel of the receiving feature allowing the band to be detached from the device body.

In one embodiment, the receiving feature includes a locking mechanism, which may be integrated with portions of either the band or the receiving feature. In one example, as the band is inserted into a receiving feature of the device, the locking mechanism interfaces with a portion of the receiving feature to lock or otherwise secure the band within the receiving feature. The locking mechanism may also be configured to interface with a releasing mechanism associated with the receiving feature. For example, a releasing mechanism may be configured to disengage or release the locking mechanism. In some implementations. actuation of the releasing mechanism causes the locking mechanism to be released and allows the band to be removed by sliding within the receiving feature.

FIG. **25**A depicts a receiving feature and band assembly as viewed from the bottom of the device body. As shown in FIG. **25**A, a receiving feature **623***a* includes an opening or channel **2501** that is formed into the body or housing of the

device. The channel **2501** is configured to receive the lug **2510** attached to an end of the band strap **621***a*. The receiving feature **623***a* may also include a locking mechanism **2530** that is configured to maintain the band strap **621***a* within the channel **2501** once it has been installed. As discussed above, the locking mechanism **2530** may be releasable by the user, which may facilitate band replacement. In this example, the locking mechanism **2530** includes a spring-loaded retaining mechanism that engages the lug **2510** to retain the lug **2510** in the channel **2501** and maintain the attachment of the band strap **621***a* to the device. As shown in FIG. **25**A, the locking mechanism **2530** also includes a button located on the bottom of the housing that may be depressed by the user to release the locking mechanism and allow the lug **2510** and the band strap **621***a* to be removed from the channel **2501**. In the present example, the button of the locking mechanism **2530** is located on a curved portion of the case or housing. In some embodiments, the button of the locking mechanism **2530** is located along the centerline of the case or housing.

In some embodiments, the opening or channel **2501** of the receiving feature **623***a* includes a port or connector for receiving a mating electrical component. In some embodiments, the connector or port is covered by a label or sticker so that the inside surface of the opening or channel **2501** appears continuous. The connector or port may be located along the vertical centerline of the case or housing.

FIG. **25**B depicts an example exploded view of the receiving feature **623***a* and the lug **2510** of the band strap **621***a*. As shown in FIG. **25**B, the band strap **621***a* may be formed from a separate part and attached to lug **2510** via a pivot or other type of joint. In other embodiments, the band strap **621***a* may have an end feature that is integrally formed as part of the band strap **621***a*. As also shown in FIG. **25**B, the lug **2510** may be attached to the receiving feature **623***a* by aligning the axis of the lug **2510** with the axis of the channel **2501** and then sliding the lug **2510** into the channel **2501**.

FIG. **25**C depicts an example assembly sequence of the lug **2510** being inserted into the channel **2501** of the receiving feature **623***a*. As shown in FIG. **25**C, the lug **2510** may be positioned along the side of the receiving feature **623***a* having the lug **2510** approximately aligned with the channel **2501** of the receiving feature **623***a*. The lug **2510** (and band strap **621***a*) may then be inserted into the channel **2501** of the receiving feature **623***a* by sliding the lug **2510** along the length of the channel **2501**. Once the lug **2510** is approximately centered in the channel **2501** of the receiving feature **623***a*, the locking mechanism **2530** or other securing feature may engage, thereby retaining the lug **2510** (and band strap **621***a*) within the channel **2501**. As previously discussed, the lug **2510** (and band strap **621***a*) may be removed from the receiving feature **623***a* by depressing the button of the locking mechanism **2530**, which may disengage the lock and allow movement of the lug **2510** within the channel **2501**.

The example described above is provided with respect to one example embodiment. The geometry of the end of the band strap and/or the geometry of the channel may vary depending on the implementation. Additionally, the engagement mechanism may vary depending on the design of the band strap and the device body. The geometry or layout of the features may vary and remain within the scope of the present disclosure. Additionally, while the examples provided above are described with respect to attaching a band strap to a device body, the receiving feature (**623***a*) may be used to attach a variety of other parts to the device body. For

example a lanyard, cable, or other accessory may be attached to the device body using the receiving feature and other similar features.

12. Example Bands

As described above, a wearable electronic device may include a band that is used to secure the device to the wrist of a user. In some embodiments, the band may be formed from two band straps that are attached to the housing of the device body. The band straps may be secured around the wrist of a user by a clasp or latching mechanism. As also described above, the device may be configured to facilitate replacement of the band. This feature may allow the use of a variety of types of bands, which may adapt the device for multiple uses ranging from sporting activities to professional or social activities.

In some cases, the band may be formed from a woven textile material. In one example, the band is formed from a woven material that includes one or more strands or threads formed from a natural or synthetic material. The woven material may be formed, for example, from a plurality of warp threads that are woven around one or more weft threads. More specifically, the woven material may include a plurality of warp threads disposed along the length of the band, and at least one weft thread positioned perpendicular to, and coupled to, woven or interlaced between the plurality of warp threads. In some cases, the plurality of warp threads may run the entire length of the woven portion of the band strap. Additionally, in some cases, the at least one weft thread may include a single thread that may be continuously woven between the plurality of warp threads or, alternatively, may include a plurality of threads that may be woven between the plurality of warp threads. A weft thread that is woven between a plurality of warp threads may form consecutive cross-layers with respect to the plurality warp threads in order to form the band.

In some cases, one or more of the strands or threads may be a metallic or conductive material. This may improve the strength of the band and may also facilitate coupling with magnetic elements, such as a metallic clasp. In some cases, other elements may be woven into the band, including, for example, product identifying elements, decorative elements, or functional components.

In other embodiments, the band may be formed from a metallic mesh material. In one example, the metallic mesh is formed from an array of links that are interlocked to form a sheet of fabric. Some or all of the links in the mesh may be formed from a ferromagnetic material, which may facilitate magnetic engagement with a magnetic clasp. In some cases, each link of the mesh is formed from a section of metallic filament that is bent or formed into a closed shape. Each closed shape may be interlocked with one or more adjacent links to form a portion of the sheet or fabric. In some cases, a metallic filament is formed around a series of rods or pins that are disposed at a regular spacing within the mesh. In some cases, one or more strands or filaments that may be formed from a ferromagnetic material are woven or integrated with the links of the mesh.

In other examples, the band may be formed from a sheet of material. For example, the band may be formed from a synthetic leather, leather, or other animal hide. Additionally or alternatively, the band may be formed from a polymer material, an elastomer material, or other type of plastic or synthetic. In some cases, the band is formed from a silicone sheet material.

The clasp that is used to attach the free ends of the band straps may vary depending on the material that is used and the construction of the band. For example, as mentioned

above, a metallic mesh material may use a metallic clasp to join the ends of the band. Additionally, a leather band may be integrated with magnetic and/or ferromagnetic components and may include a magnetic clasp. In some embodiments, the free ends of the band straps are secured using a buckle or tang on a first band strap that is configured to interface with a hole or aperture in a second band strap. A variety of other clasp configurations may also be used.

13. Example Display

For the purposes of the following description, the described device **100** is one example of that shown and discussed above with respect to FIGS. **2-7**. However, certain features of the device **100**, including the external surface geometry, may be simplified or vary with respect to aspects of the device **100** discussed above. As described above, the device includes a display disposed within the housing or enclosure. The device may be formed from a liquid crystal display (LCD), organic light emitting diode (OLED) display, organic electroluminescence (OEL) display, or other type of display device. The display may be used to present visual information to the user, including, for example, a graphical user interface, notifications, health statistics, and the like. In some cases, the display may be configured to present the current time and date similar to a traditional watch or timepiece.

In some embodiments, the display is formed from an organic light emitting diode (OLED) display element. An active region of the display may include an array of light-emitting display pixels **2604** such as array **2602**, shown in FIG. **26**. Pixels **2604** may be arranged in rows and columns in array **2602** and may be controlled using a pattern of control lines. Each pixel may include a light-emitting element such as organic light-emitting diode **2612** and associated control circuitry **2610**. Control circuitry **2610** may be coupled to the data lines **2606** and gate lines **2608** so that control signals may be received from driver circuitry, which may be implemented as an integrated circuit. Although described as an OLED display, certain embodiments may implement other display technology, such as LCD displays and the like.

To the extent that multiple functionalities, operations, and structures are disclosed as being part of, incorporated into, or performed by device **100**, it should be understood that various embodiments may omit any or all such described functionalities, operations, and structures. Thus, different embodiments of the device **100** may have some, none, or all of the various capabilities, apparatuses, physical features, modes, and operating parameters discussed herein

Although the disclosure above is described in terms of various exemplary embodiments and implementations, it should be understood that the various features, aspects and functionality described in one or more of the individual embodiments are not limited in their applicability to the particular embodiment with which they are described, but instead can be applied, alone or in various combinations, to one or more of the other embodiments of the invention, whether or not such embodiments are described and whether or not such features are presented as being a part of a described embodiment. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments but instead defined by the claims herein presented.

We claim:

1. An electronic watch comprising:

a housing formed from a metal material and defining a rear opening along a rear portion of the housing;

a touch-sensitive display positioned at least partially within the housing;

a band coupled to the housing and configured to couple the electronic watch to a user;

a cover formed from a dielectric material and forming a seal along the rear opening of the housing;

an optical sensor positioned within the housing and configured to transmit an optical signal through the dielectric material of the cover;

a charging coil positioned within the housing and configured to receive wireless power through the dielectric material of the cover;

a first electrode positioned along a rear surface of the electronic watch; and

a second electrode positioned along the rear surface of the electronic watch, wherein:

the electronic watch is configured to measure a heart rate using the optical sensor, and

the electronic watch is configured to measure an electrocardiogram using the first electrode and the second electrode.

2. The electronic watch of claim **1**, wherein:

the cover defines at least one window for the optical sensor; and

the cover protrudes outward from a rear housing surface of the housing.

3. The electronic watch of claim **1**, wherein:

the cover is formed from a transparent substrate; and

the transparent substrate comprises one or more of a glass or a sapphire material.

4. The electronic watch of claim **1**, wherein:

the electronic watch further comprises a first magnet positioned within the housing;

the first magnet is configured to couple to a second magnet positioned within a charging dock; and

the first and second magnets are configured to maintain alignment of the electronic watch with respect to the charging dock.

5. The electronic watch of claim **1**, wherein:

the electronic watch further comprises a near-field communication system; and

the near-field communication system is configured to transmit signals through one or more of the housing or the cover.

6. The electronic watch of claim **1**, wherein:

the cover defines a convex exterior profile; and

the convex exterior profile facilitates alignment between the cover and a mating surface of an external wireless charging device.

7. A wearable electronic device comprising:

a housing formed from a conductive material and defining a first opening opposite to a second opening;

a band attached to the housing and configured to secure the wearable electronic device to a user;

a display positioned in the first opening;

a cover comprising a non-conductive material and positioned over the second opening, the cover forming a portion of an exterior surface of the wearable electronic device;

a biosensor module positioned below the cover configured to pass an optical signal through a window defined within the non-conductive material of the cover; and

a wireless charging receive coil aligned with the second opening and below the cover, the wireless charging receive coil configured to inductively couple to an external wireless charging device through the non-conductive material of the cover.

8. The wearable electronic device of claim **7**, wherein:
the window is a first window;
the cover defines a second window; and
the biosensor module comprises:
a light source configured to emit light toward a region of skin of the user through the first window: and
a detector configured to receive light reflected from the region of the skin through the second window.

9. The wearable electronic device of claim **7**, wherein:
the biosensor module comprises:
at least one light source; and
a set of detectors; and
the at least one light source and the set of detectors are configured to operate as a photoplethysmogram (PPG) sensor.

10. The wearable electronic device of claim **7**, wherein:
the cover protrudes outward from a rear surface of the housing;
the cover defines a convex exterior profile; and
the convex exterior profile facilitates alignment between the cover and a mating surface of the external wireless charging device.

11. The wearable electronic device of claim **10**, wherein:
the cover forms a waterproof seal with the housing along a perimeter of the cover.

12. The wearable electronic device of claim **7**, wherein:
the wearable electronic device further comprises a first magnet positioned within the housing and below the cover;
the external wireless charging device comprises a second magnet; and
the first and second magnets are configured to maintain alignment between the wearable electronic device and the external wireless charging device during a charging operation.

13. The wearable electronic device of claim **7**, wherein:
the wearable electronic device further comprises:
a first electrode positioned along a rear surface of the wearable electronic device; and
a second electrode positioned along the rear surface of the wearable electronic device; and
the wearable electronic device is configured to measure an electrocardiographic characteristic using the first and second electrodes.

14. An electronic device comprising:
a housing defining a first opening and a second opening;
a display positioned at least partially within the first opening;
a biosensor module aligned with the second opening;
a wireless charging receive coil positioned within the housing and aligned with the second opening;
a battery operably coupled to the wireless charging receive coil; and
a cover formed from an optically transparent material and disposed over the biosensor module and the wireless charging receive coil, wherein:
the electronic device is configured to receive wireless power through the optically transparent material of the cover using the wireless charging receive coil; and
the electronic device is configured to measure a heart rate of a user through the optically transparent material of the cover using the biosensor module.

15. The electronic device of claim **14**, wherein:
the biosensor module includes an array of optical components; and
the cover defines an array of windows, each window of the array of windows aligned with a respective optical component of the array of optical components.

16. The electronic device of claim **14**, wherein:
the biosensor module comprises:
a light source; and
a detector;
the light source and the detector are configured to measure changes in light absorption by a region of skin of the user;
the electronic device is configured to compute the heart rate using the measured changes in light absorption; and
the display is configured to display information associated with the heart rate.

17. The electronic device of claim **14**, wherein:
the electronic device further comprises:
a first electrode disposed along an exterior of the electronic device; and
a second electrode disposed along the exterior of the electronic device; and
the first and second electrodes are configured to measure an electrocardiographic characteristic of the user.

18. The electronic device of claim **14**, wherein:
the electronic device further comprises a magnet that is configured to magnetically couple the electronic device to an external inductive power transmitter dock through the cover.

19. The electronic device of claim **14**, wherein the cover protrudes outward from a rear surface of the housing to facilitate alignment between the cover and a mating surface of an external wireless charging device.

* * * * *

EXHIBIT D

US010987054B2

(12) **United States Patent**
Pandya et al.

(10) **Patent No.: US 10,987,054 B2**
(45) **Date of Patent: *Apr. 27, 2021**

(54) **WEARABLE ELECTRONIC DEVICE WITH ELECTRODES FOR SENSING BIOLOGICAL PARAMETERS**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **16/841,543**

(22) Filed: **Apr. 6, 2020**

(65) **Prior Publication Data**

US 2020/0229761 A1 Jul. 23, 2020

Related U.S. Application Data

(63) Continuation of application No. 16/193,836, filed on Nov. 16, 2018, now Pat. No. 10,610,157, which is a (Continued)

(51) **Int. Cl.**
A61B 5/00 (2006.01)
A61B 5/0404 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC .... ***A61B 5/681*** (2013.01); ***A61B 5/02427*** (2013.01); ***A61B 5/02438*** (2013.01); (Continued)

(58) **Field of Classification Search**
CPC A61B 5/0404; A61B 5/04085; A61B 5/02427; A61B 5/02438; A61B 5/681; A61B 5/6824; A61B 5/6898
See application file for complete search history.

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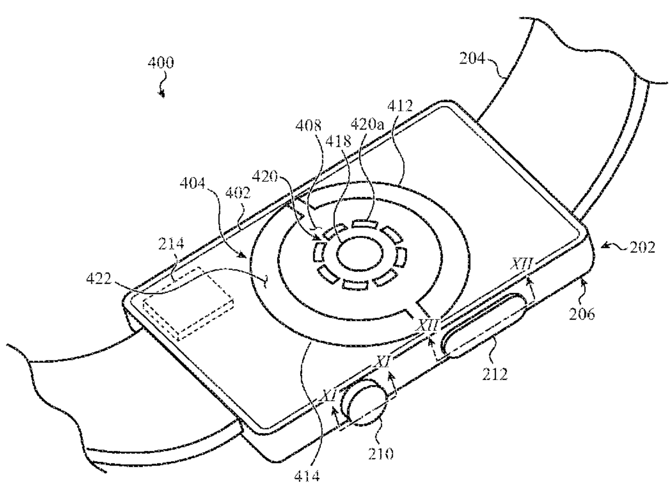
(57) **ABSTRACT**

An electronic device, such as a watch, has a housing to which a carrier is attached. The carrier has a first surface interior to the electronic device, and a second surface exterior to the electronic device. A set of electrodes is deposited on the exterior surface of the carrier. An additional electrode is operable to be contacted by a finger of a user of the electronic device while the first electrode is positioned
(Continued)



against skin of the user. The additional electrode may be positioned on a user-rotatable crown of the electronic device, on a button of the electronic device, or on another surface of the housing of the electronic device. A processor of the electronic device is operable to determine a biological parameter of the user based on voltages at the electrodes. The biological parameter may be an electrocardiogram.

20 Claims, 41 Drawing Sheets

Related U.S. Application Data

continuation of application No. 16/118,282, filed on Aug. 30, 2018.

(60) Provisional application No. 62/644,886, filed on Mar. 19, 2018, provisional application No. 62/554,196, filed on Sep. 5, 2017.

(51) **Int. Cl.**

A61B 5/0408	(2006.01)
A61B 5/024	(2006.01)
A61B 5/044	(2006.01)
G06F 1/16	(2006.01)
G04G 9/00	(2006.01)
G04G 21/02	(2010.01)
G04G 21/08	(2010.01)

(52) **U.S. Cl.**

CPC ***A61B 5/044*** (2013.01); ***A61B 5/0404*** (2013.01); ***A61B 5/04085*** (2013.01); ***G04G 9/0005*** (2013.01); ***G04G 21/025*** (2013.01); ***G04G 21/08*** (2013.01); ***G06F 1/163*** (2013.01)

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2020/0100684	A1	4/2020	Lamego

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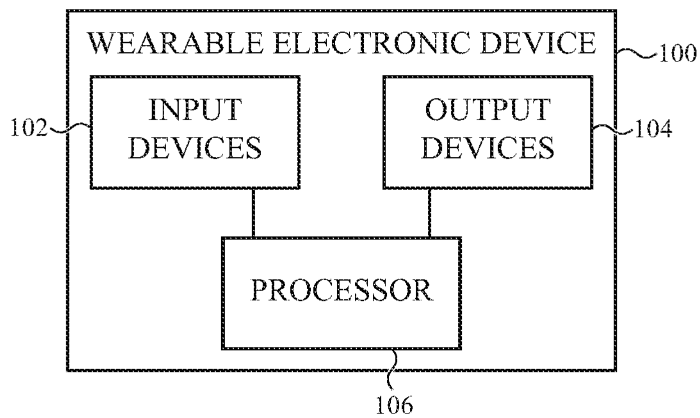
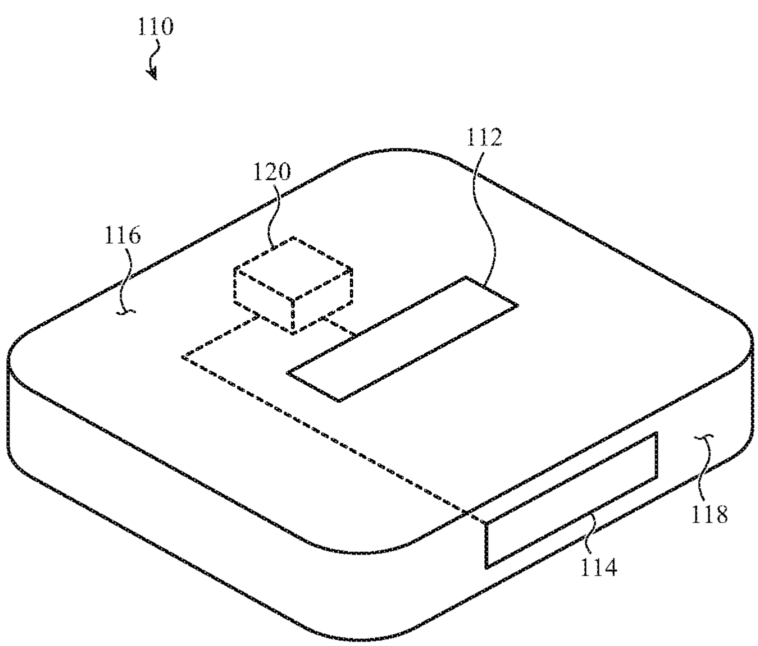

WEARABLE ELECTRONIC DEVICE
100
102
INPUT DEVICES
OUTPUT DEVICES
104
PROCESSOR
106

FIG. 1A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120
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118
114

FIG. 1B

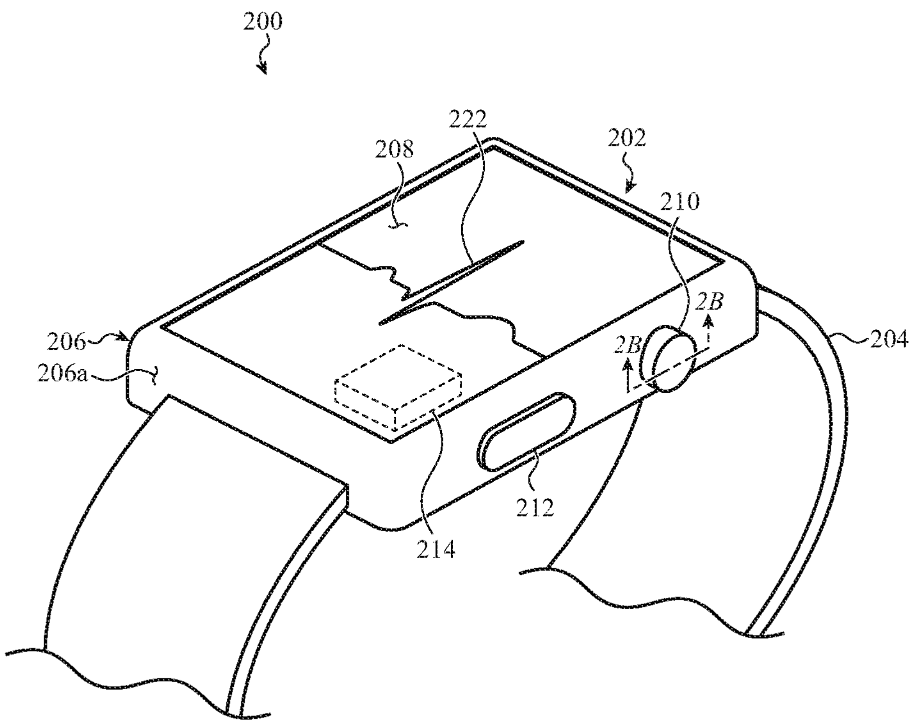


FIG. 2A

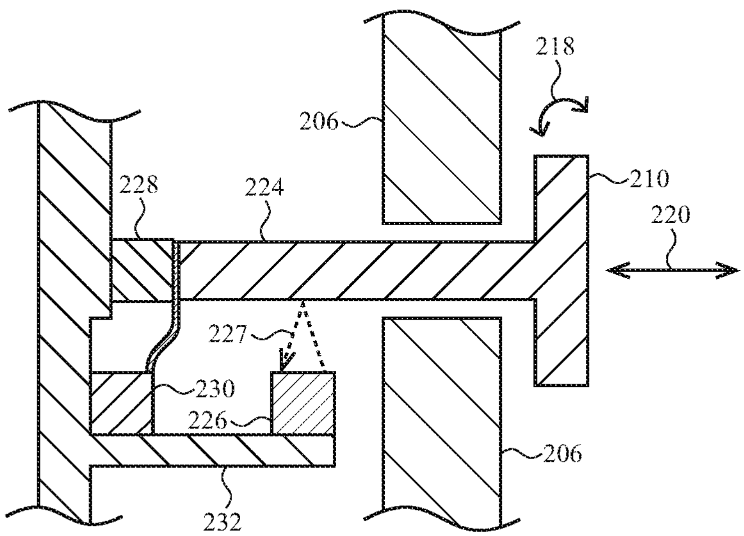


FIG. 2B

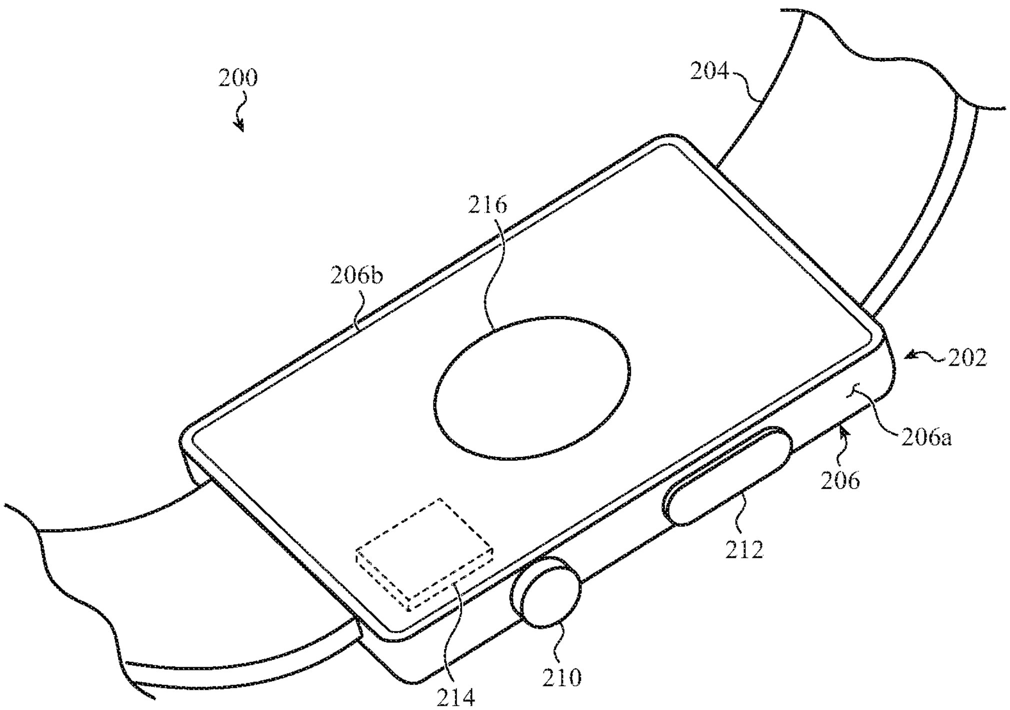


FIG. 2C

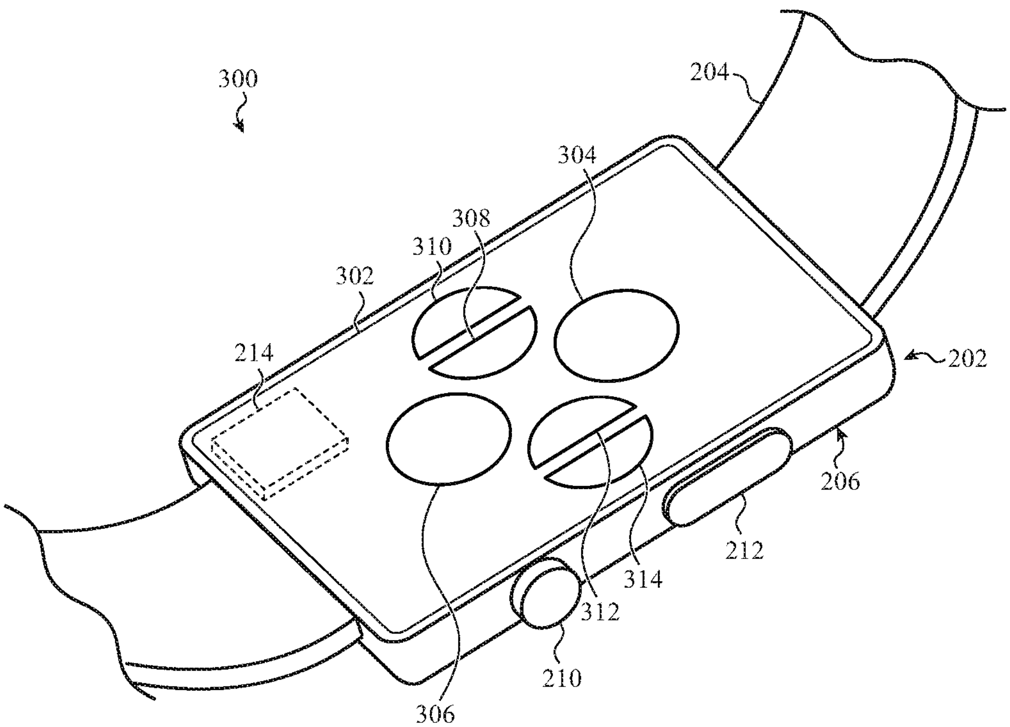
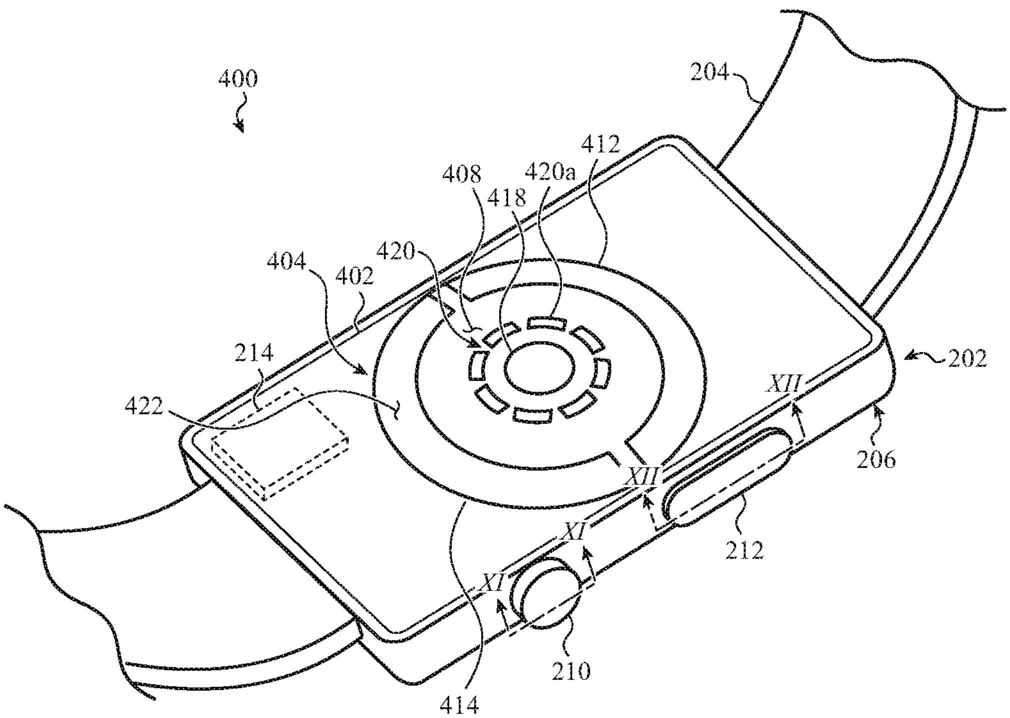


FIG. 3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402
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202
XII
XII
206
XI
XI
212
210
414

FIG. 4A

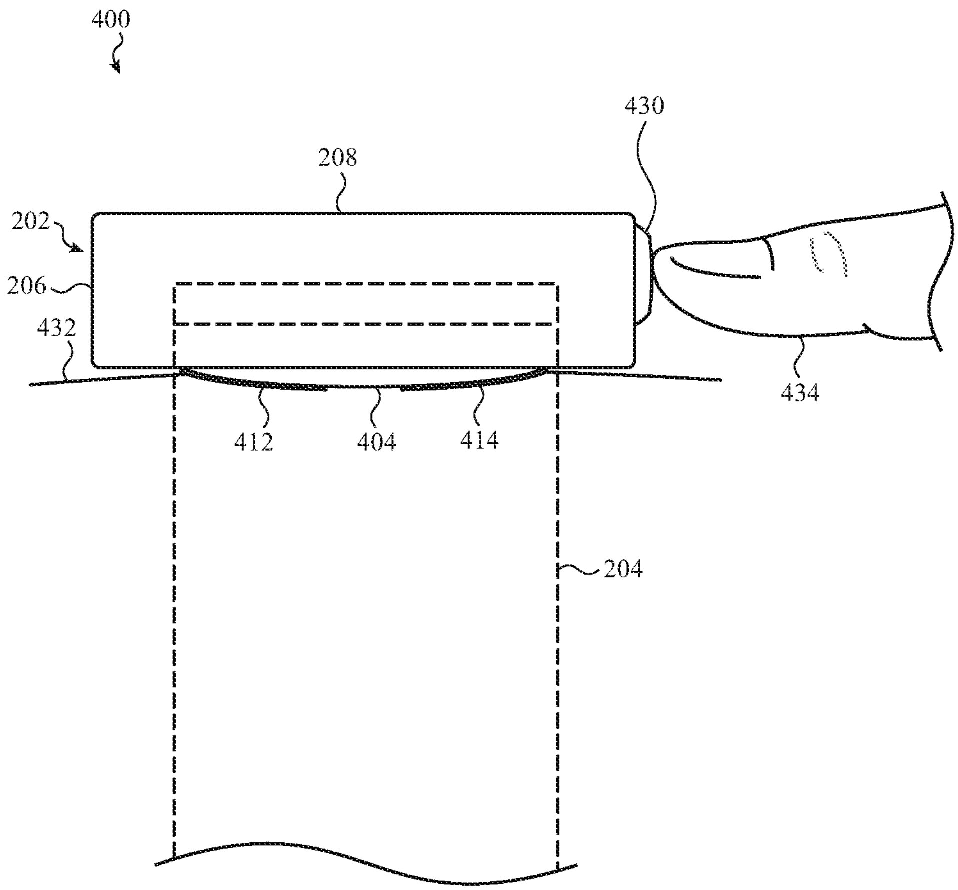
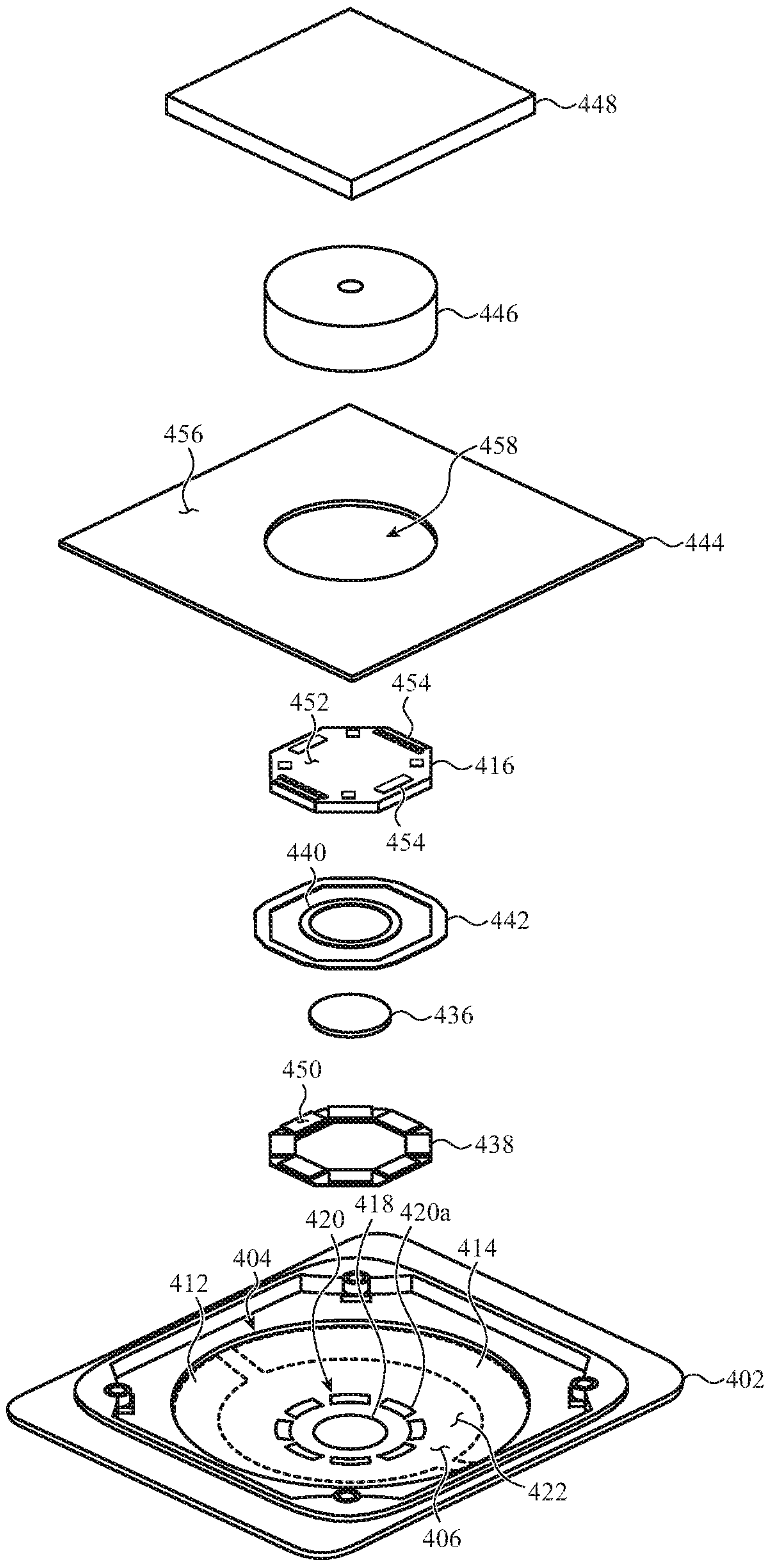


FIG. 4B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420a
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422
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FIG. 4C

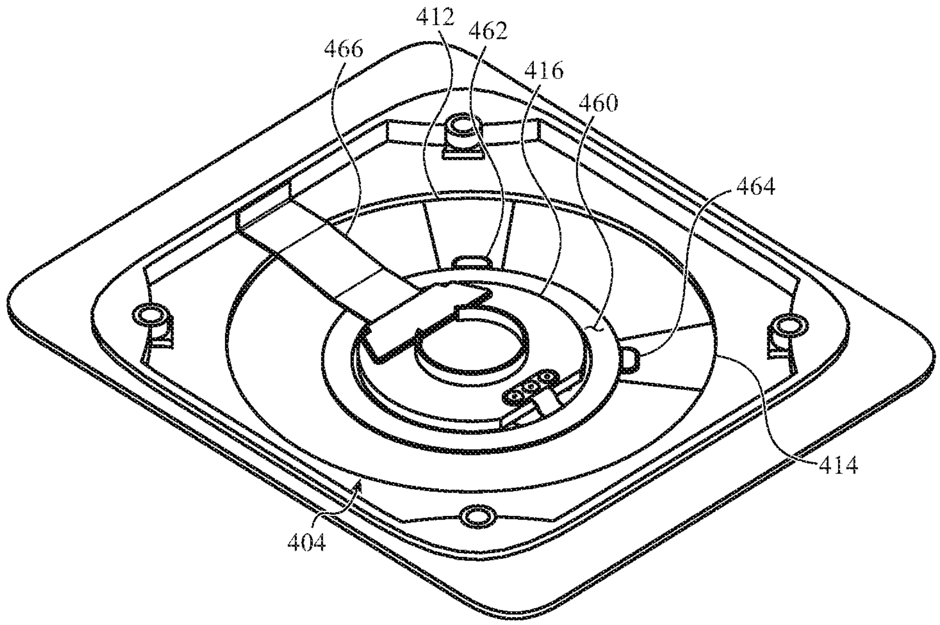


FIG. 4D

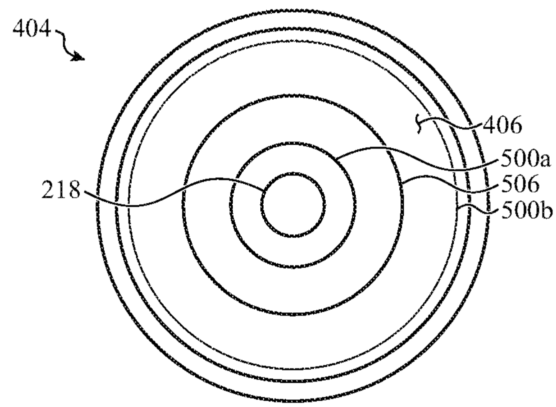


FIG. 5A

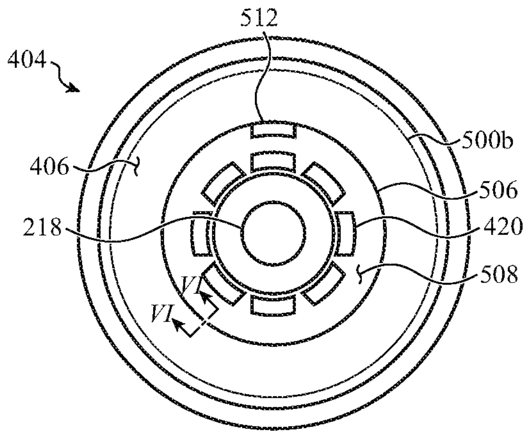


FIG. 5B

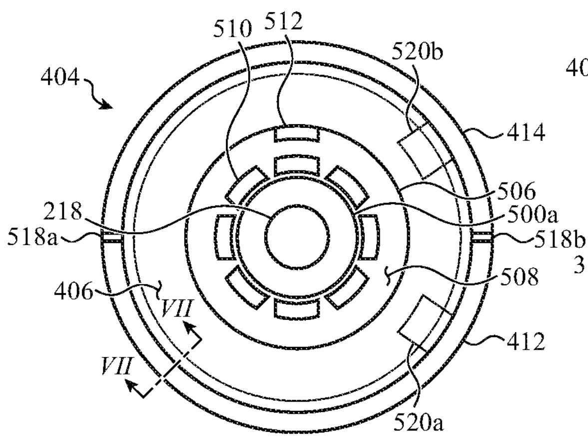


FIG. 5C

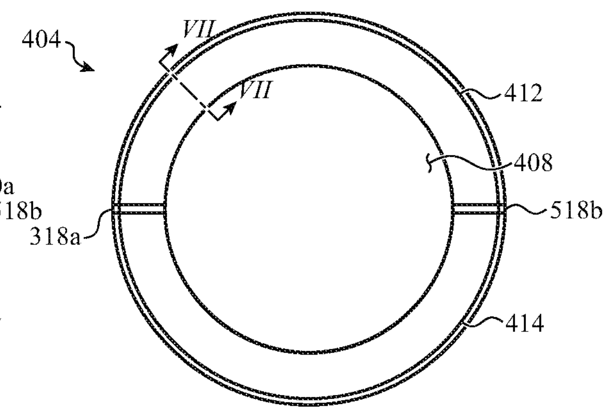


FIG. 5D

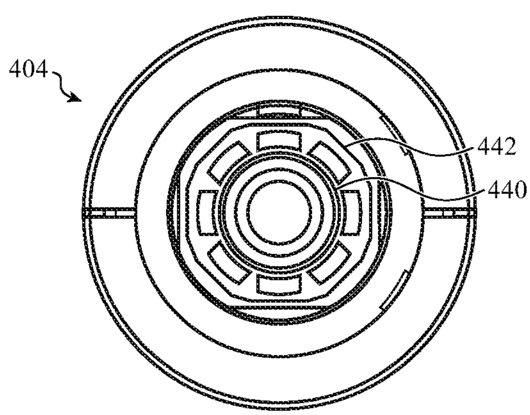


FIG. 5E

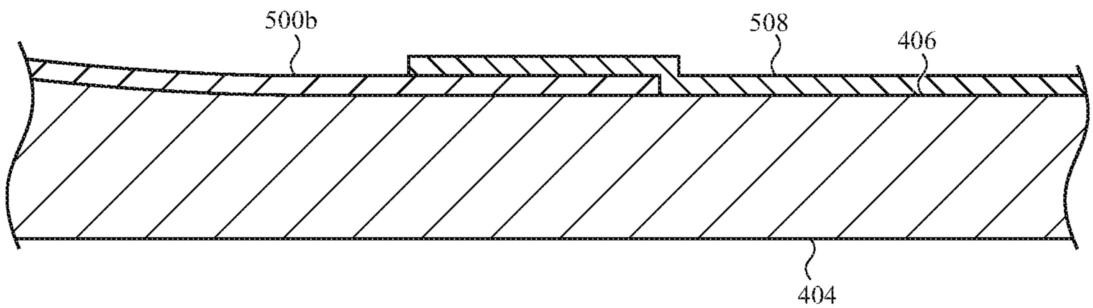


FIG. 6

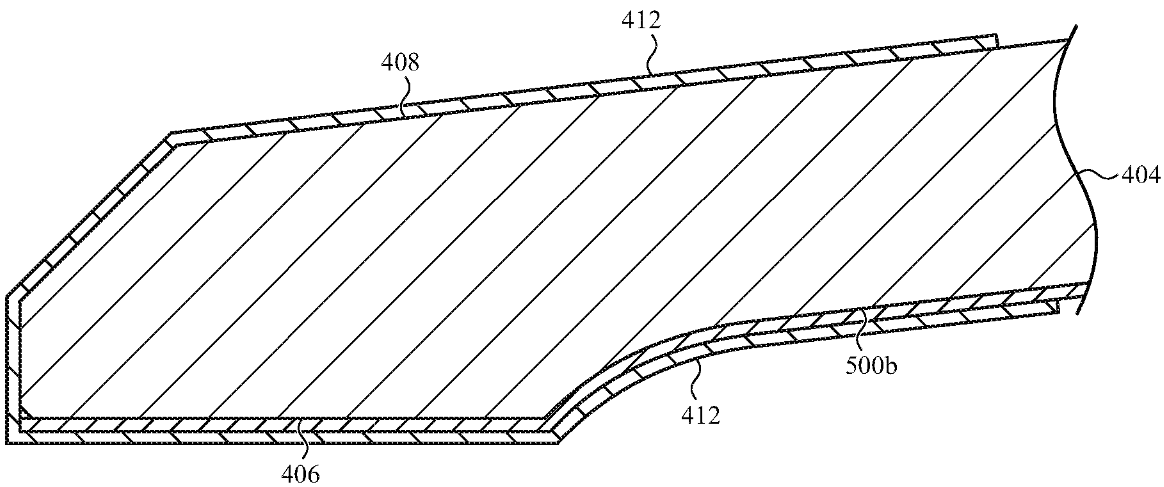


FIG. 7

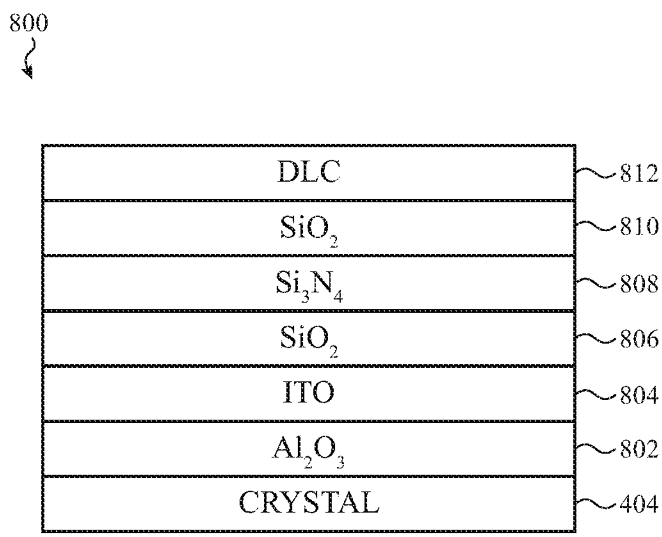

800
DLC
812
SiO_2
810
Si_3N_4
808
SiO_2
806
ITO
804
Al_2O_3
802
CRYSTAL
404

FIG. 8

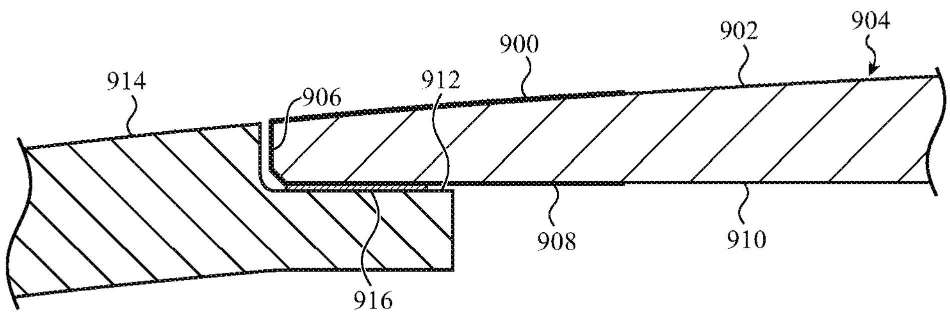


FIG. 9A

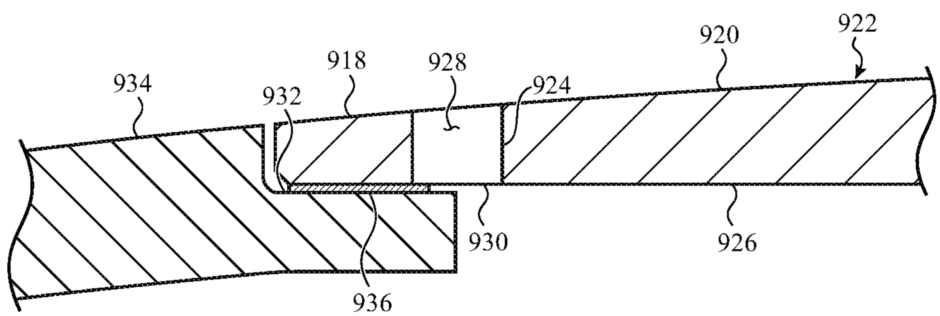


FIG. 9B

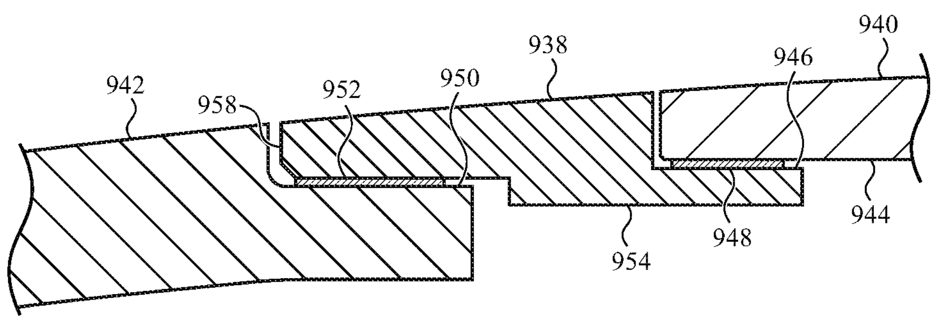


FIG. 9C

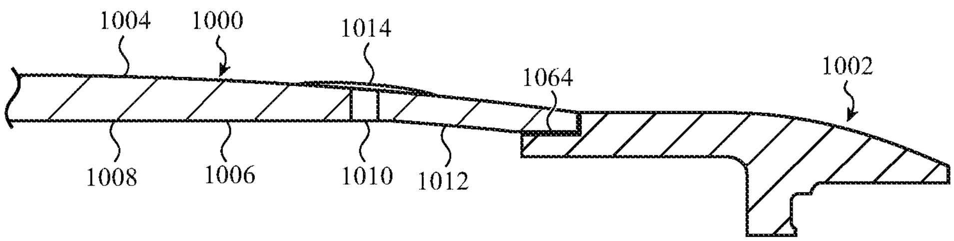


FIG. 10A

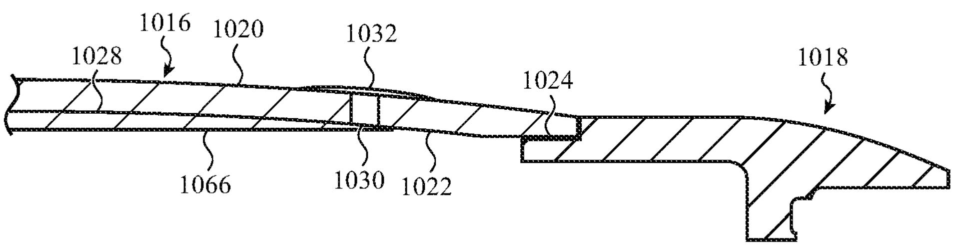


FIG. 10B

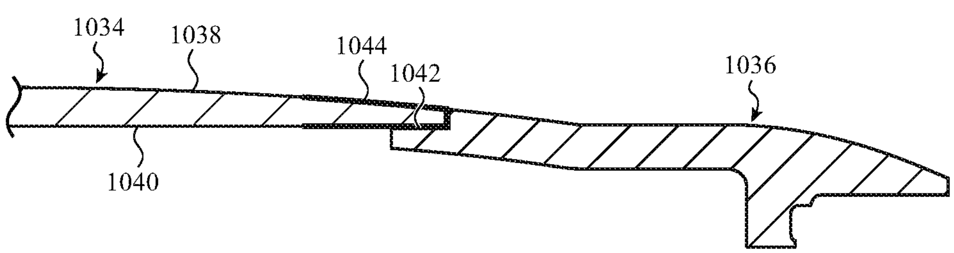


FIG. 10C

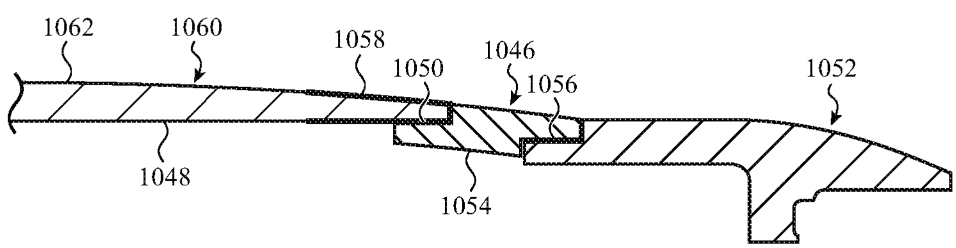


FIG. 10D

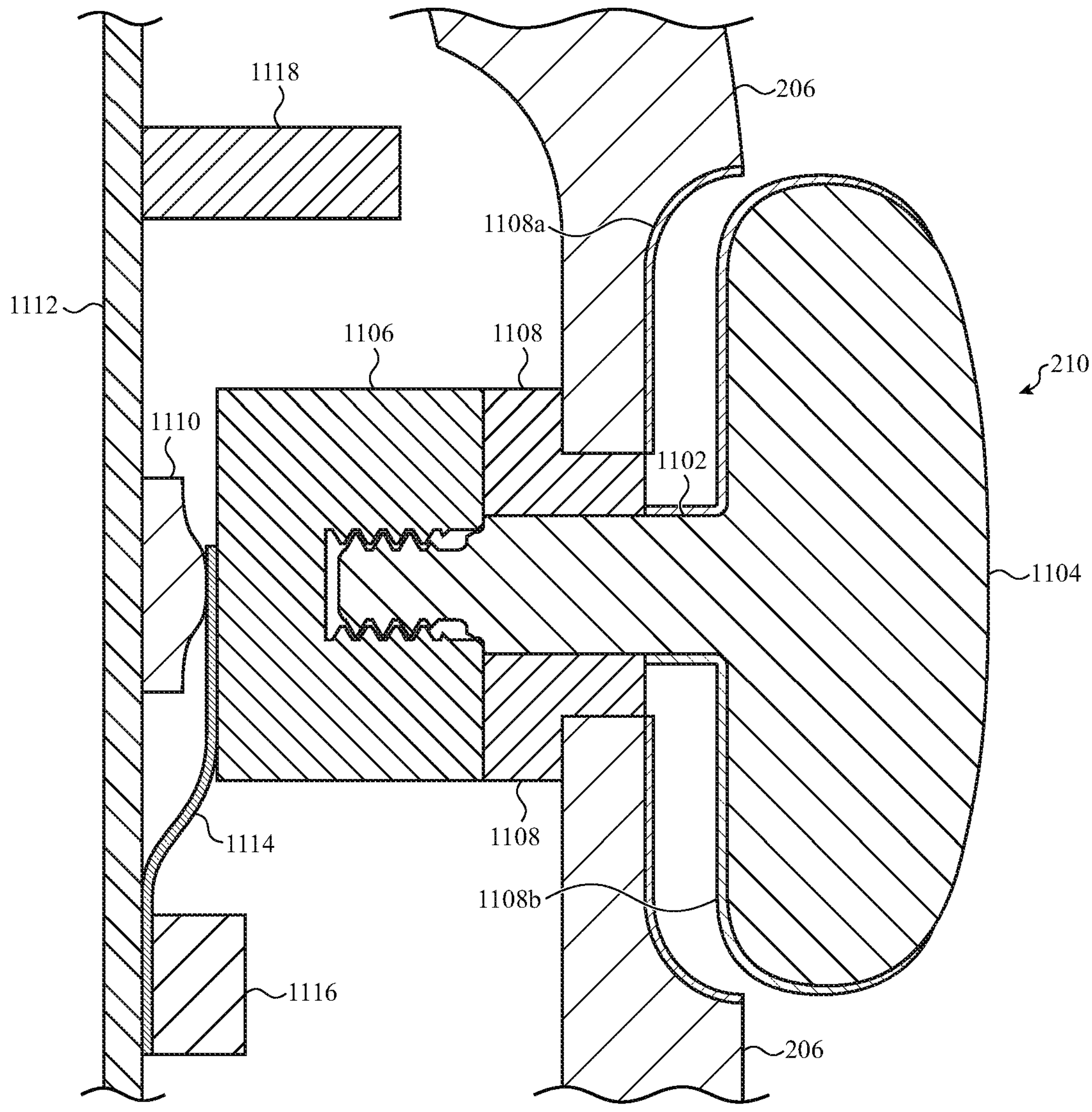
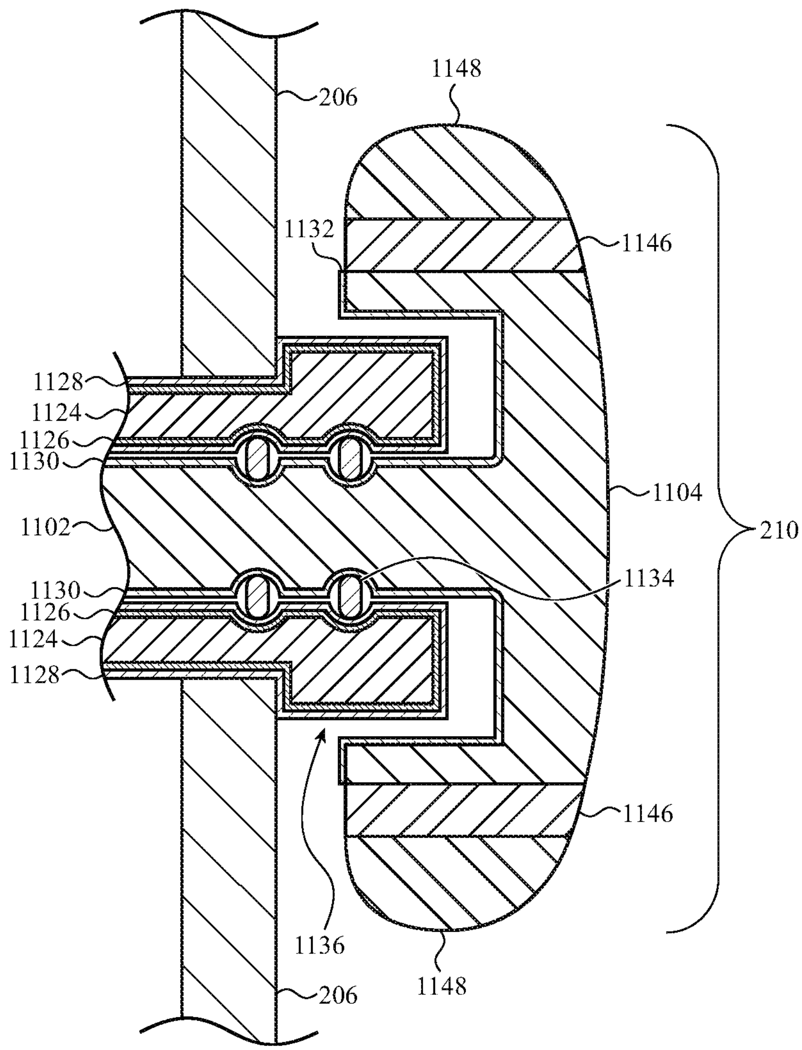

1118
206
1108a
1112
1106
1108
210
1110
1102
1104
1114
1108
1108b
1116
206

FIG. 11A


1148
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1130
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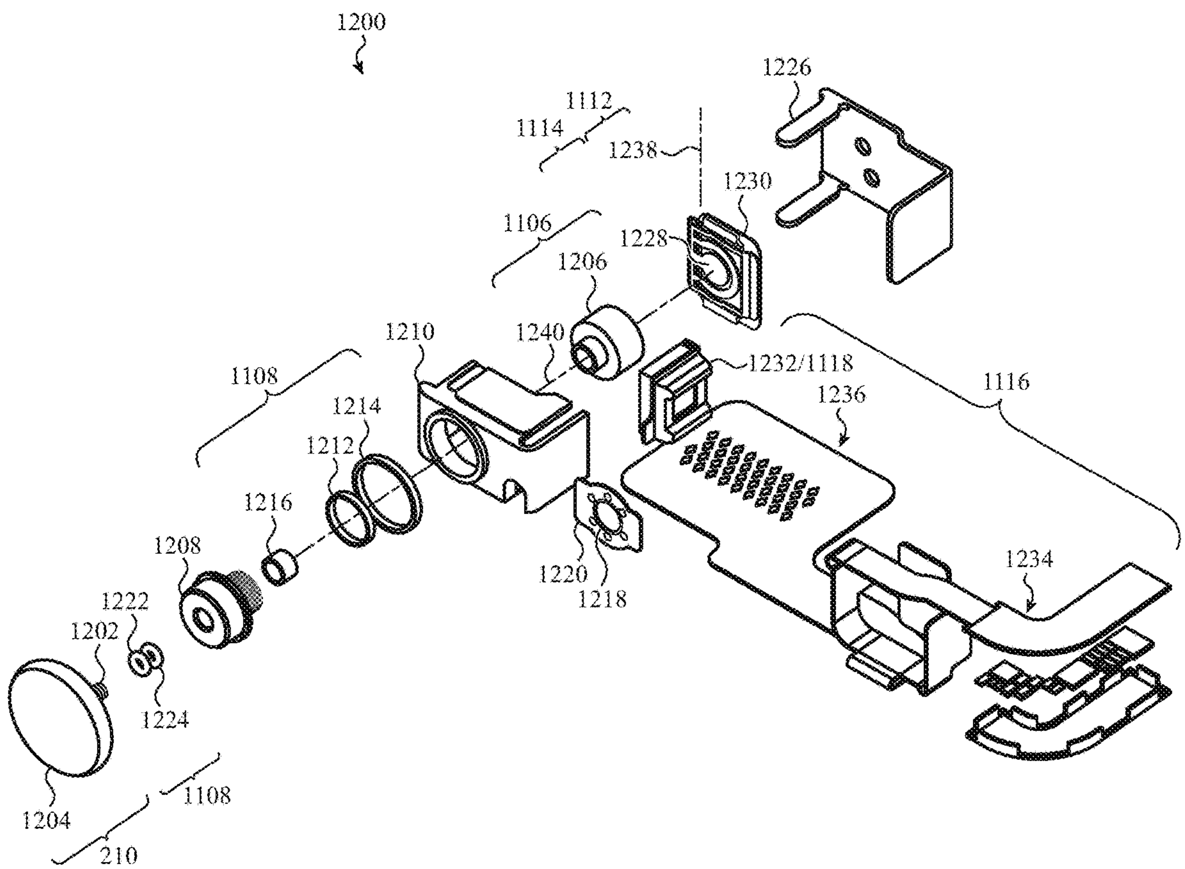
1124
1128
1146
1136
1148
206

FIG. 11B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1228
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1210
1240
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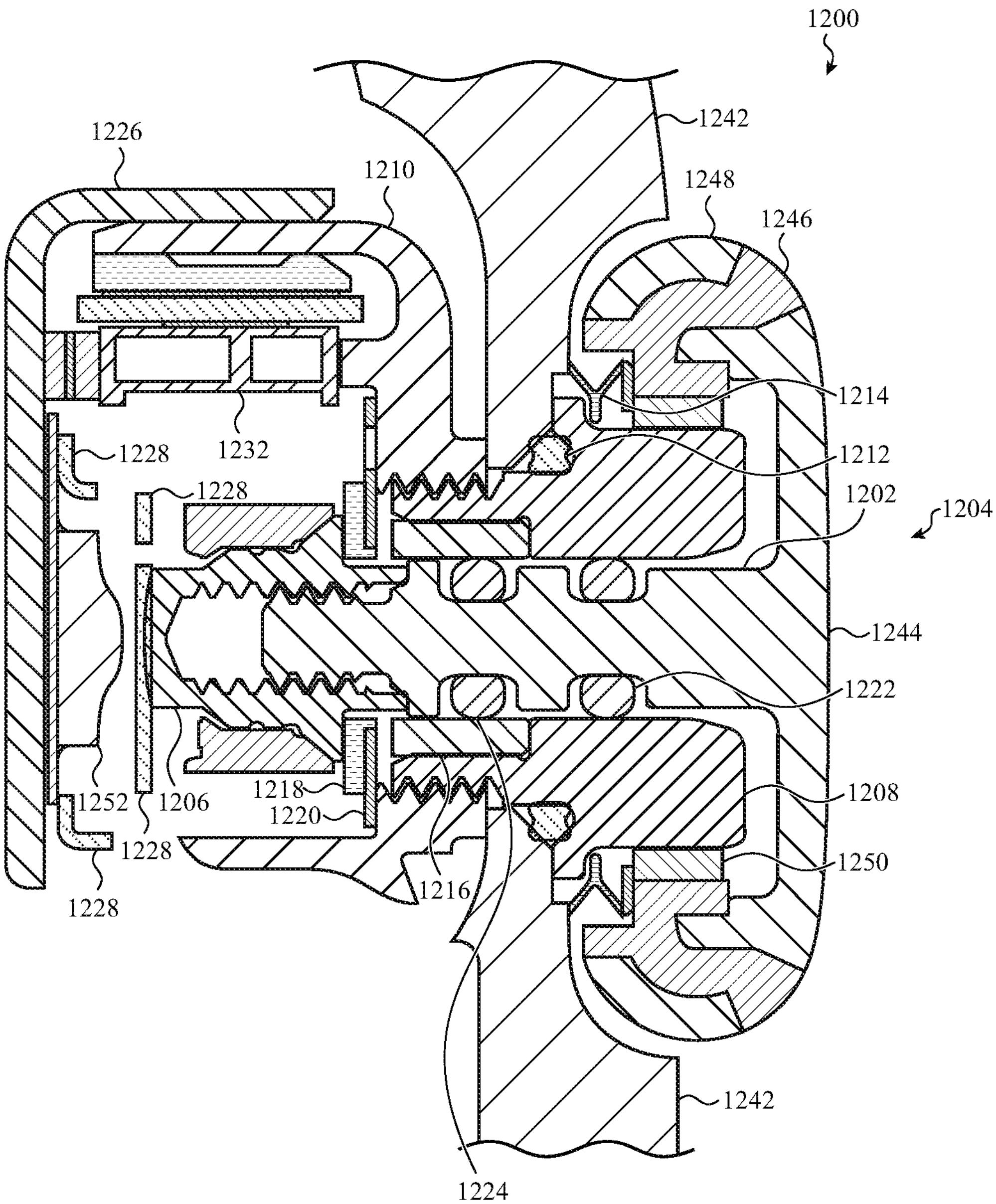
1108
1236
1116
1214
1212
1216
1208
1220
1218
1234
1222
1202
1224
1108
1204
210

FIG. 12A


1200
1242
1226
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1248
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1214
1232
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1212
1228
1202
1204
1244
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1208
1218
1252
1206
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1228
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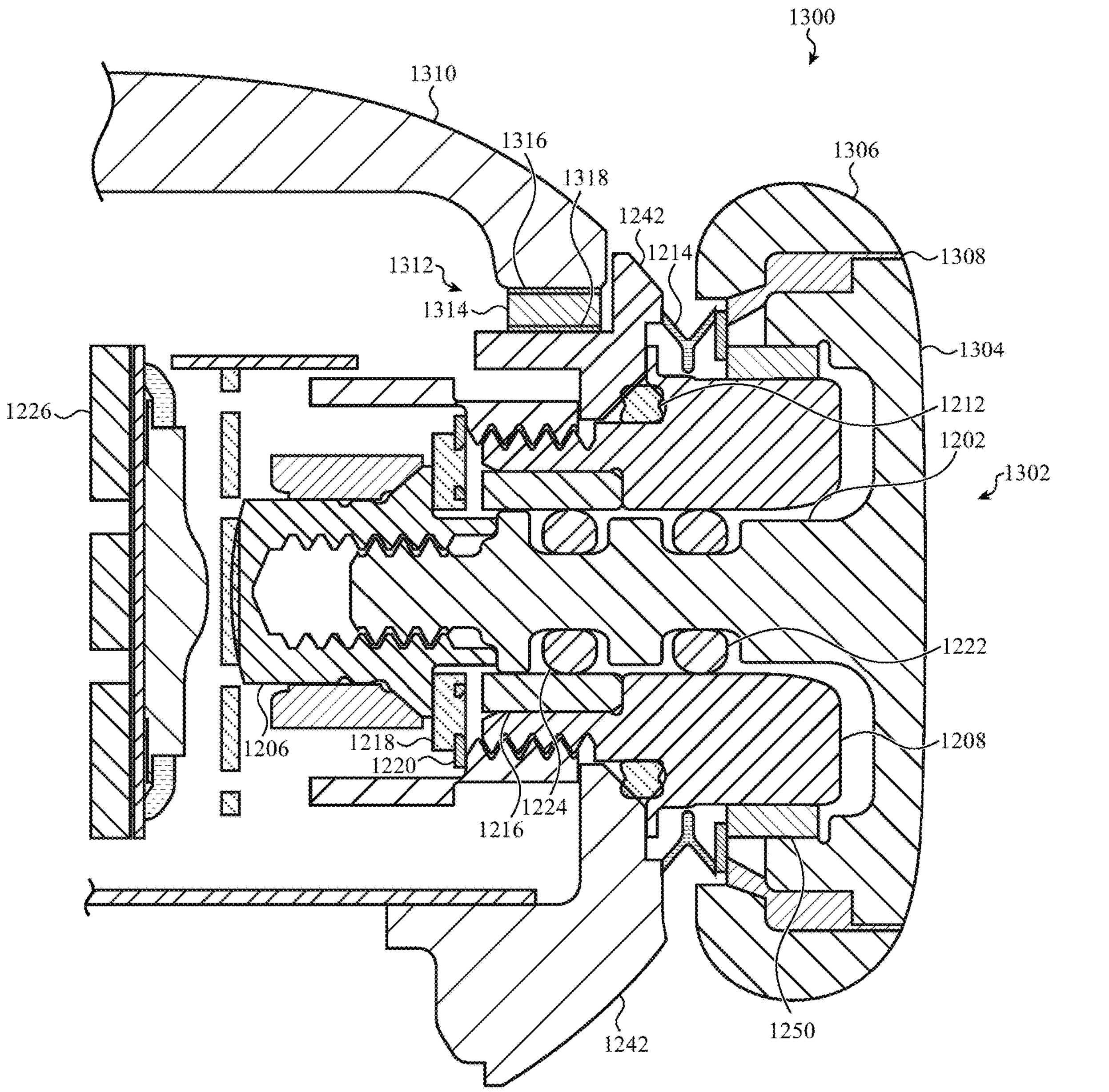
1216
1228
1242
1224

FIG. 12B



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1318
1306
1242
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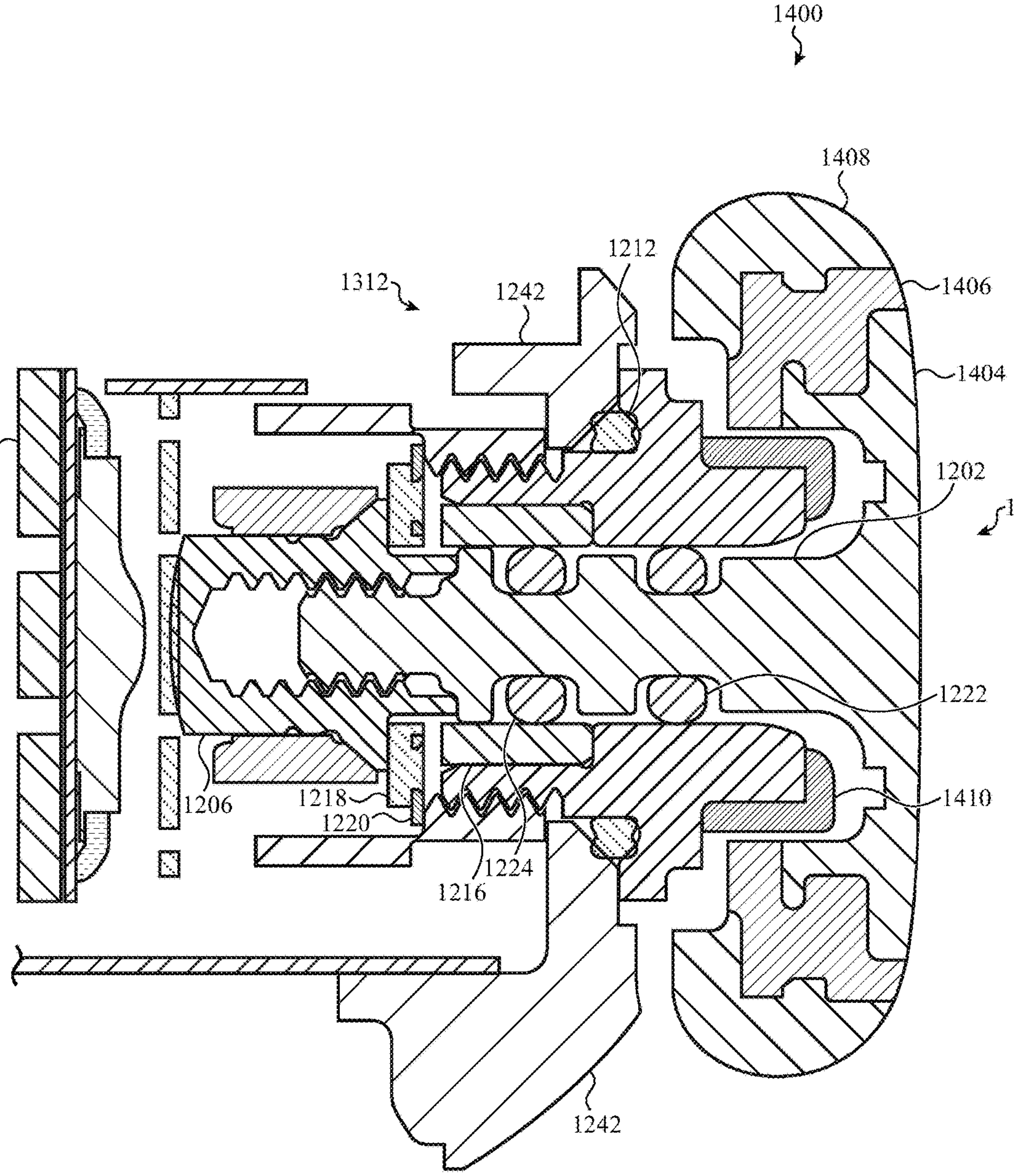
1314
1304
1226
1212
1202
1302
1222
1208
1218
1206
1220
1224
1216
1242
1250

FIG. 13


1400
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1406
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1226
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1222
1206
1218
1220
1224
1216
1410
1242

FIG. 14

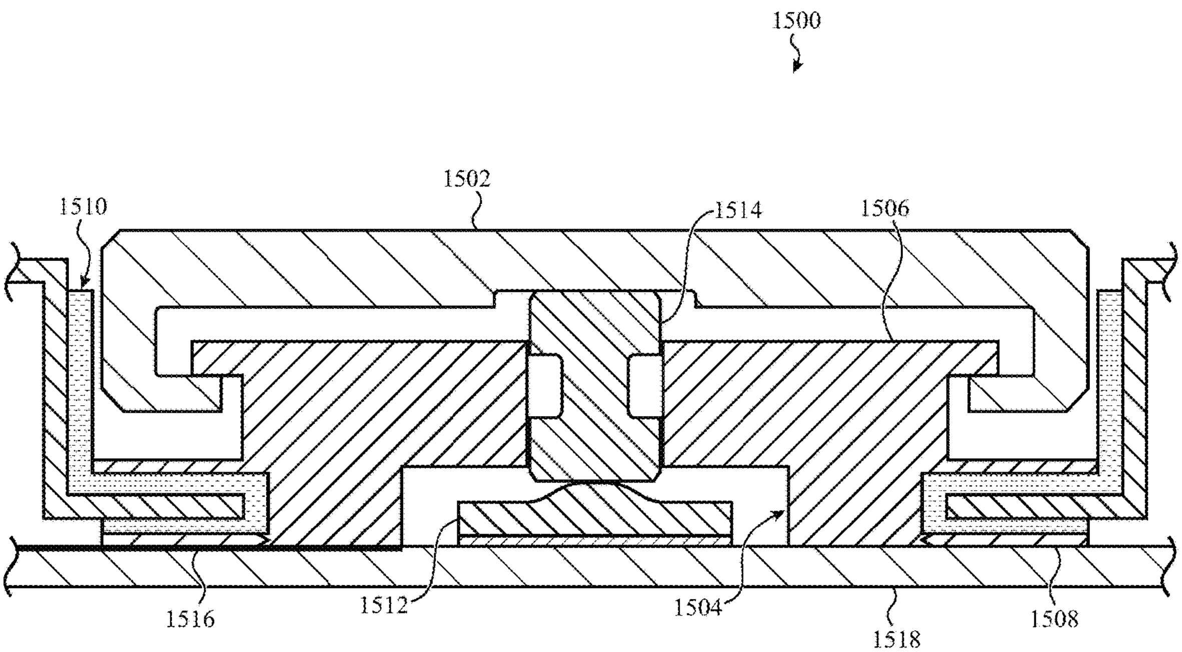
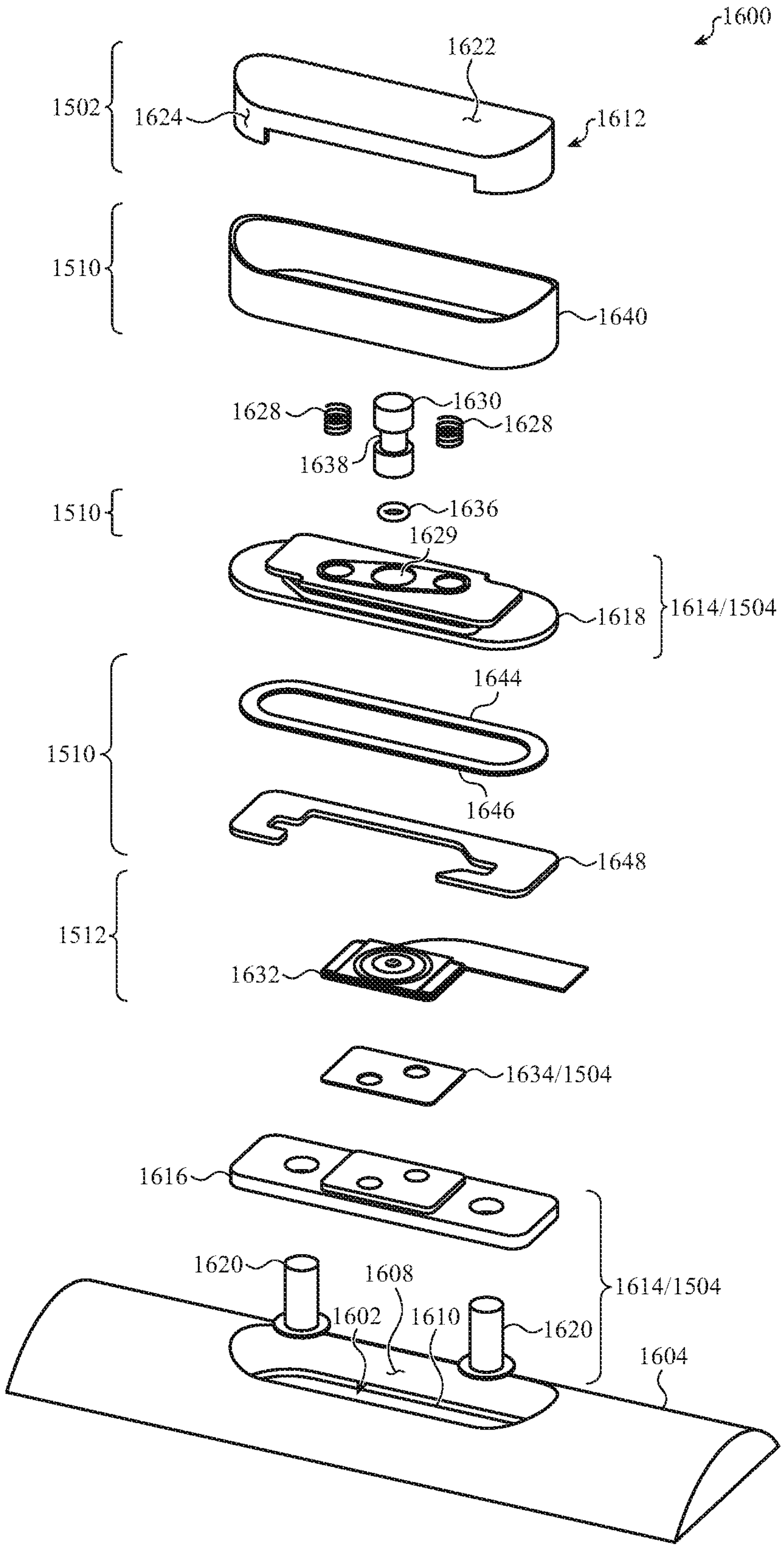


FIG. 15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1628
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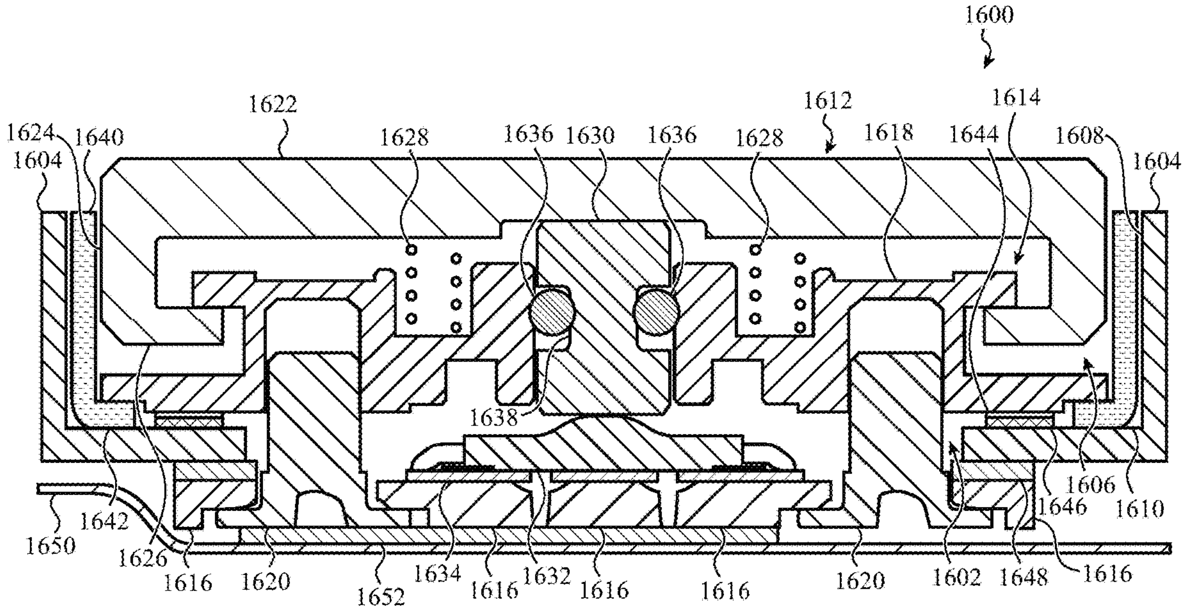
1628
1638
1510
1636
1629
1618
1614/1504
1644
1510
1646
1648
1512
1632
1634/1504
1616
1620
1608
1614/1504
1602
1610
1620
1604

FIG. 16A


1600
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1604
1638
1606
1646
1610
1642
1650
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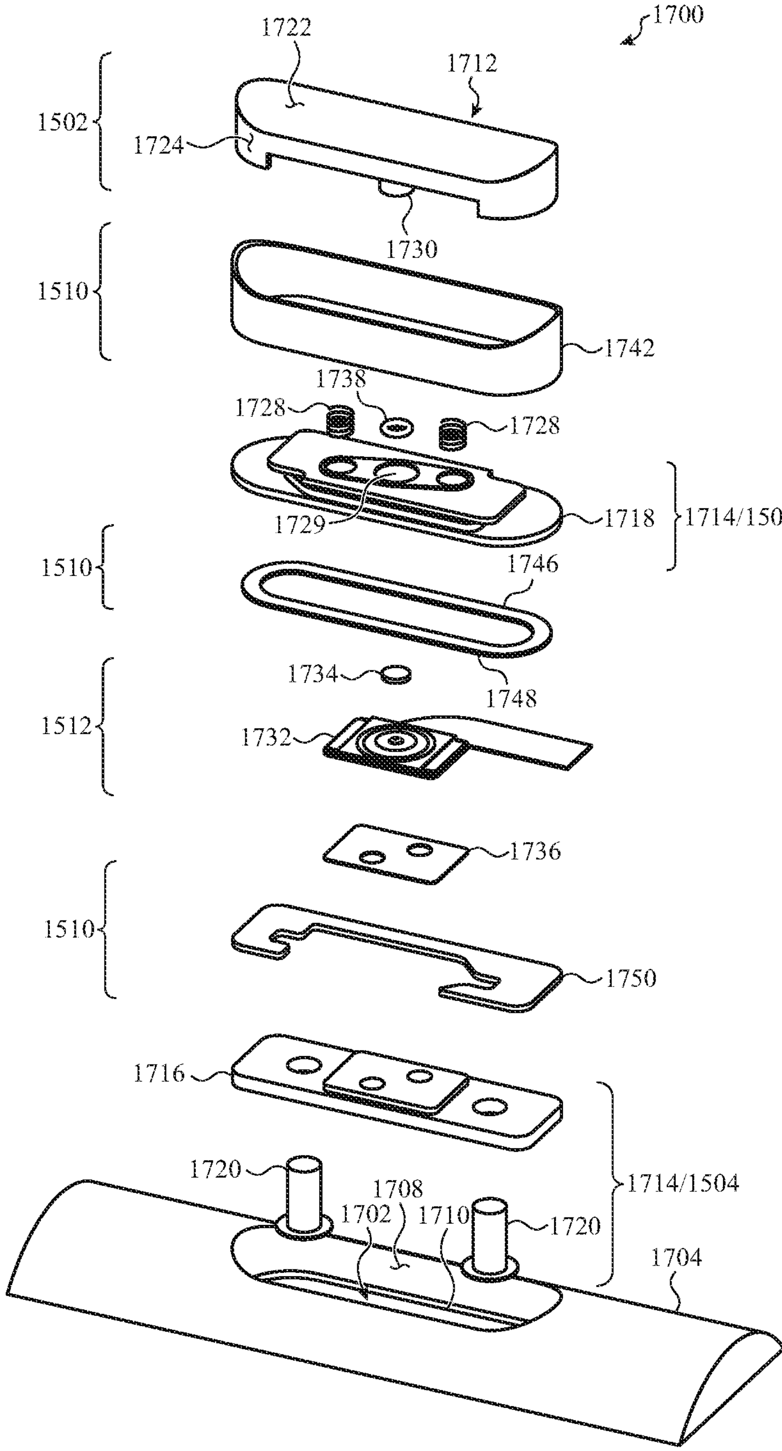
1616
1632
1616
1616
1620
1602
1648
1616

FIG. 16B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1728
1718
1714/1504
1729
1510
1746
1734
1748
1512
1732
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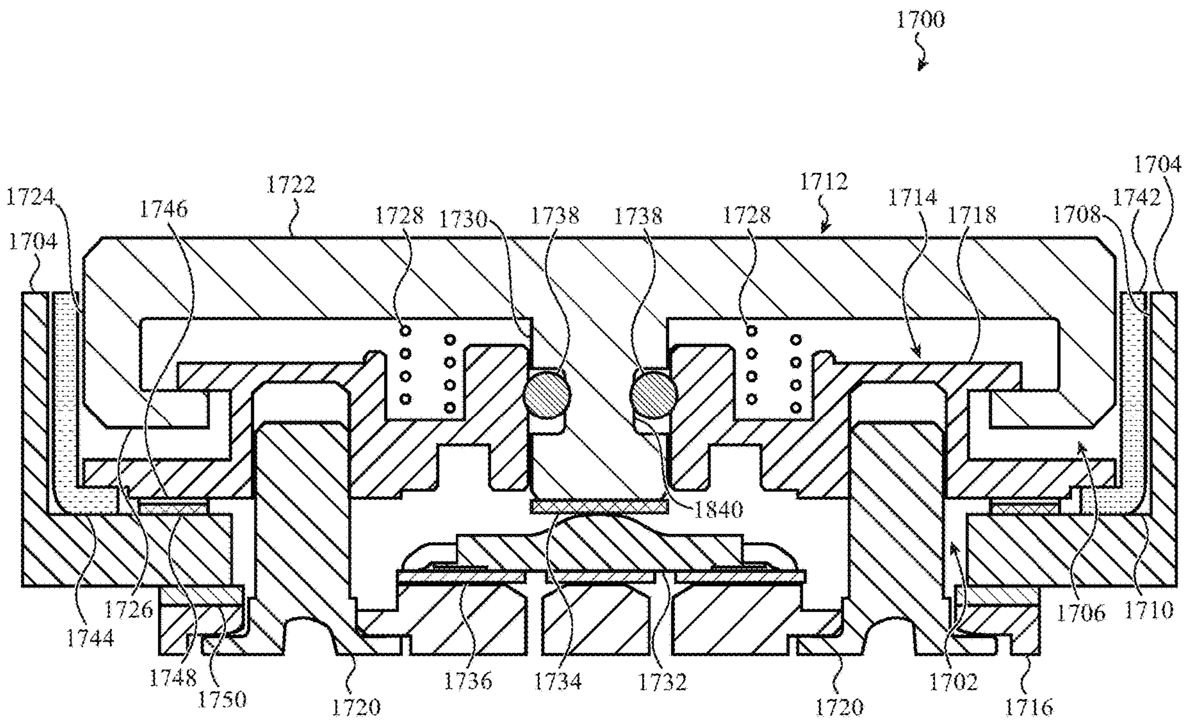
1510
1750
1716
1720
1708
1702
1710
1720
1714/1504
1704

FIG. 17A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1704
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1736
1734
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1720
1702
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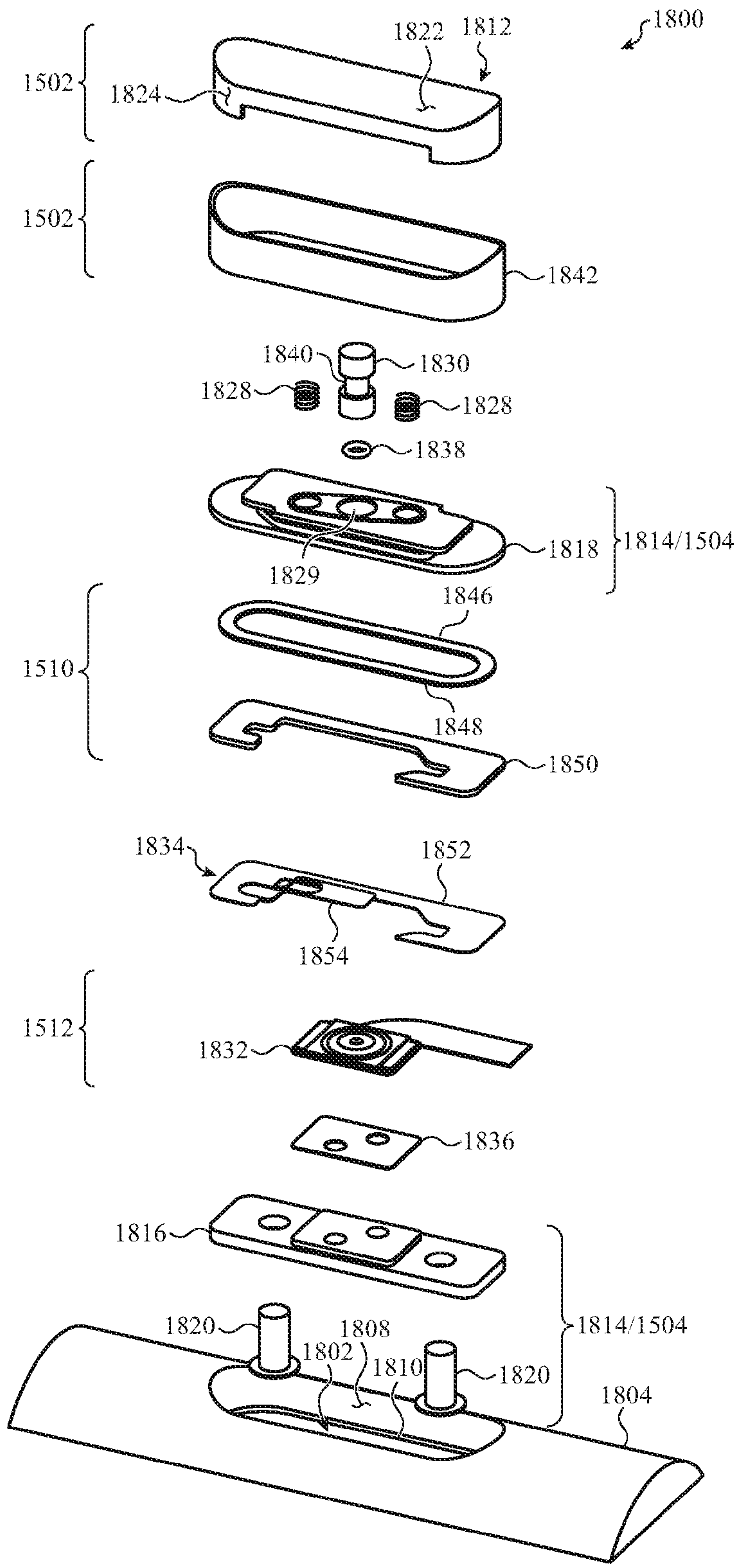
1706
1710

FIG. 17B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1818
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1848
1850
1834
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1816
1814/1504
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1808
1802
1810
1820
1804

FIG. 18A

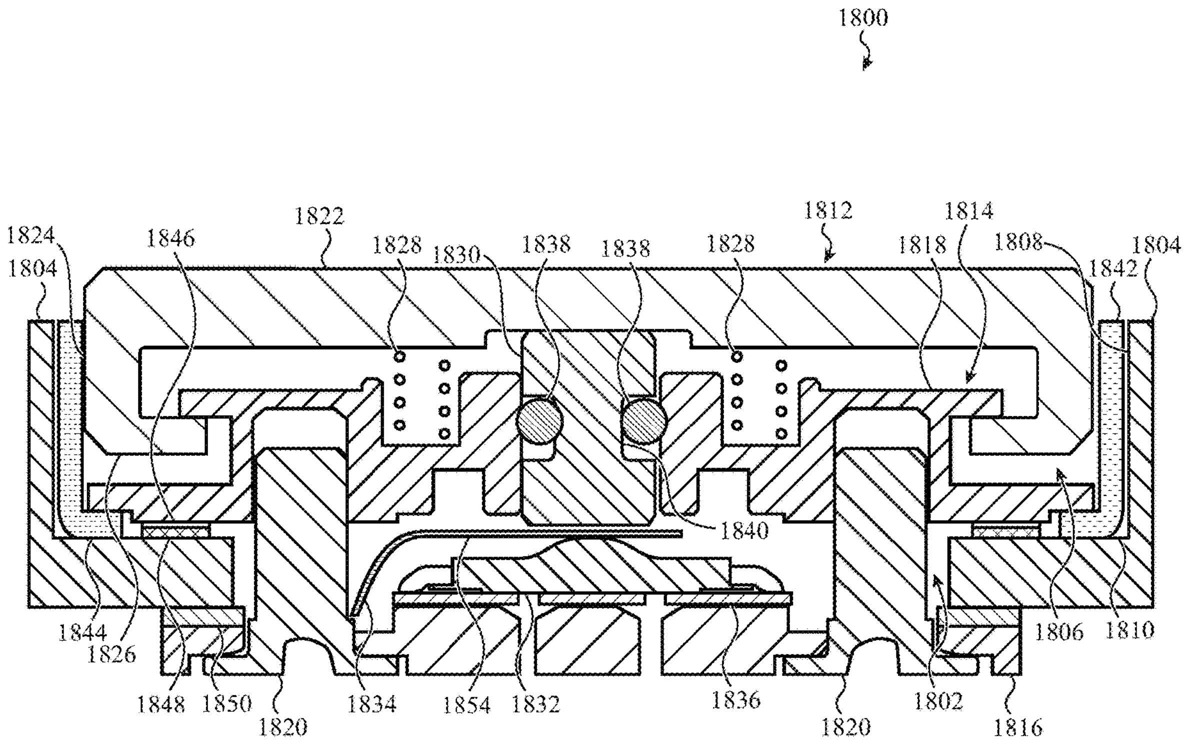
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FIG. 18B

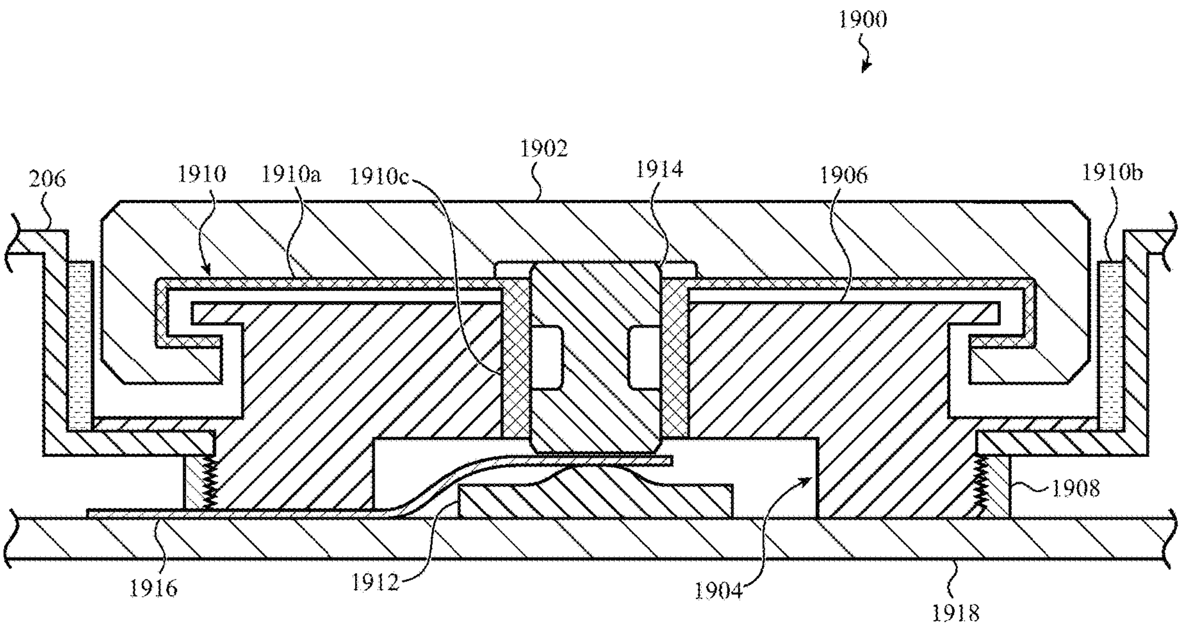
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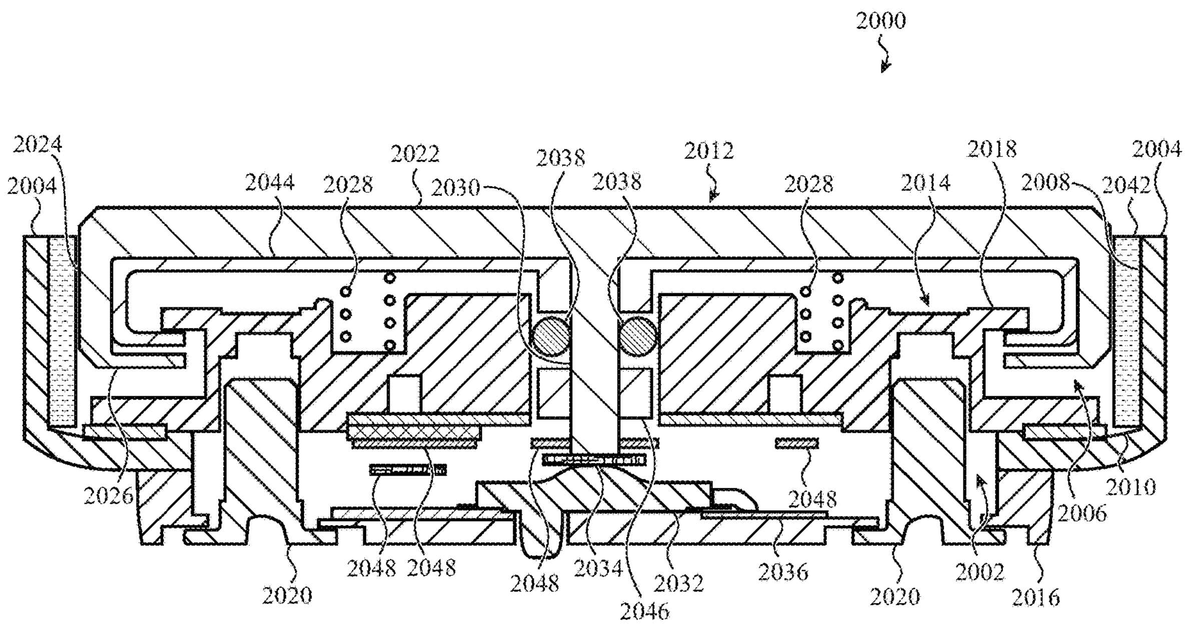
FIG. 19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2036
2048
2020
2020
2002
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2010

FIG. 20

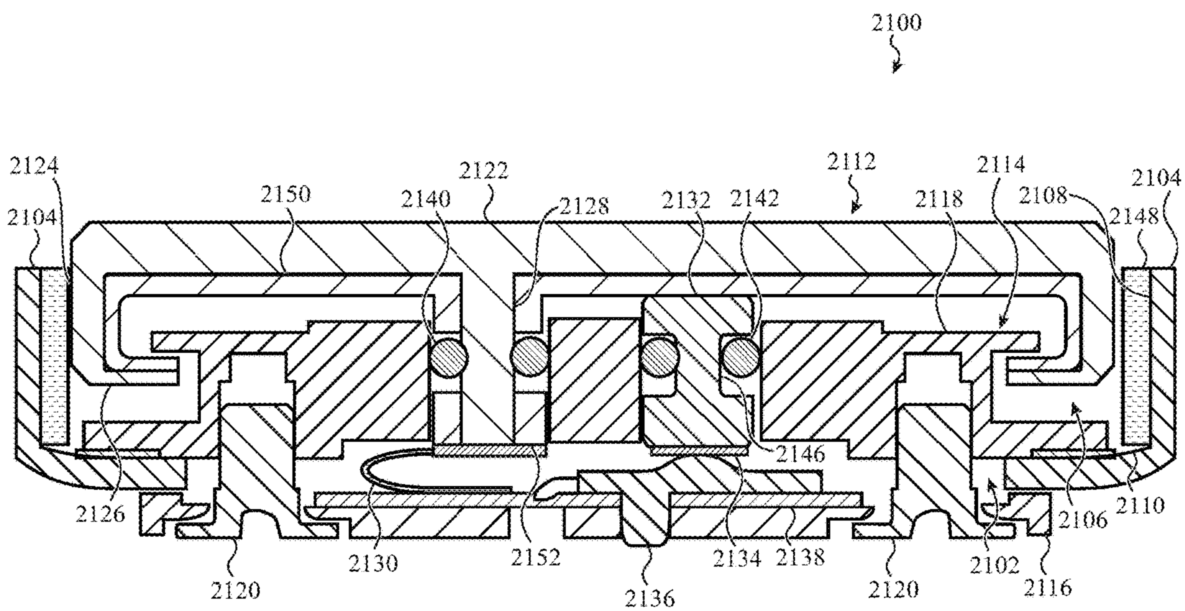
2100
2124
2104
2150
2140
2122
2128
2132
2142
2112
2118
2114
2108
2104
2148
2146
2126
2130
2152
2134
2138
2136
2120
2120
2102
2116
2106
2110

FIG. 21

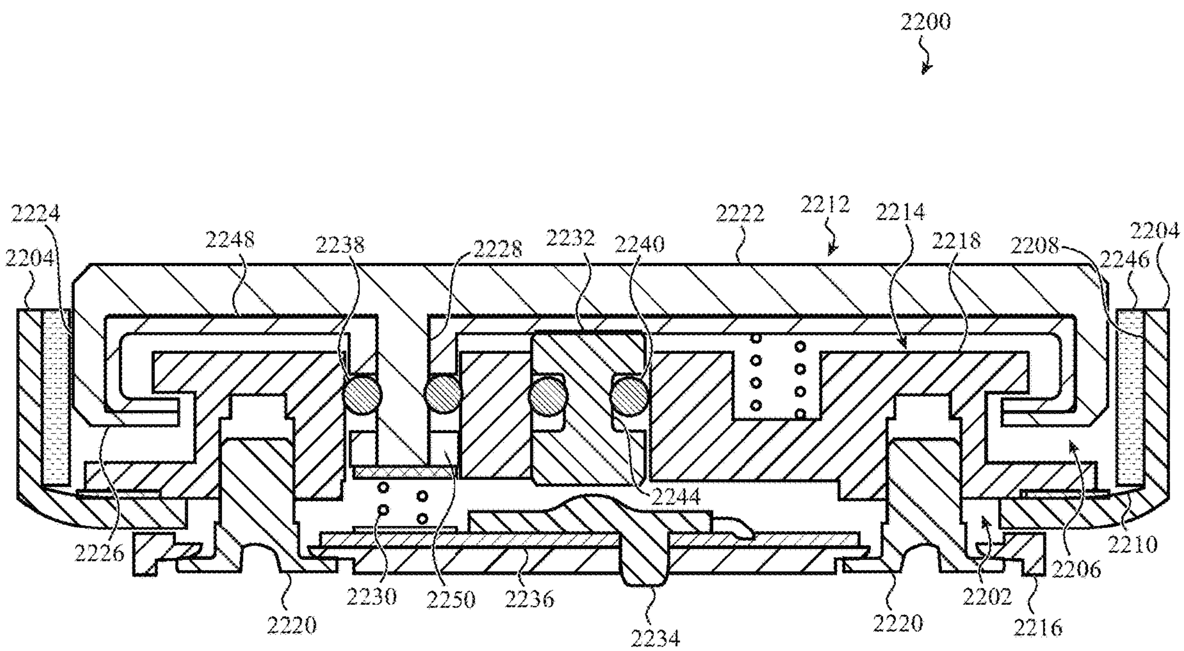
2200
2224
2204
2248
2238
2228
2232
2240
2222
2212
2214
2218
2208
2246
2204
2226
2244
2210
2206
2230
2250
2236
2202
2220
2234
2220
2216

FIG. 22

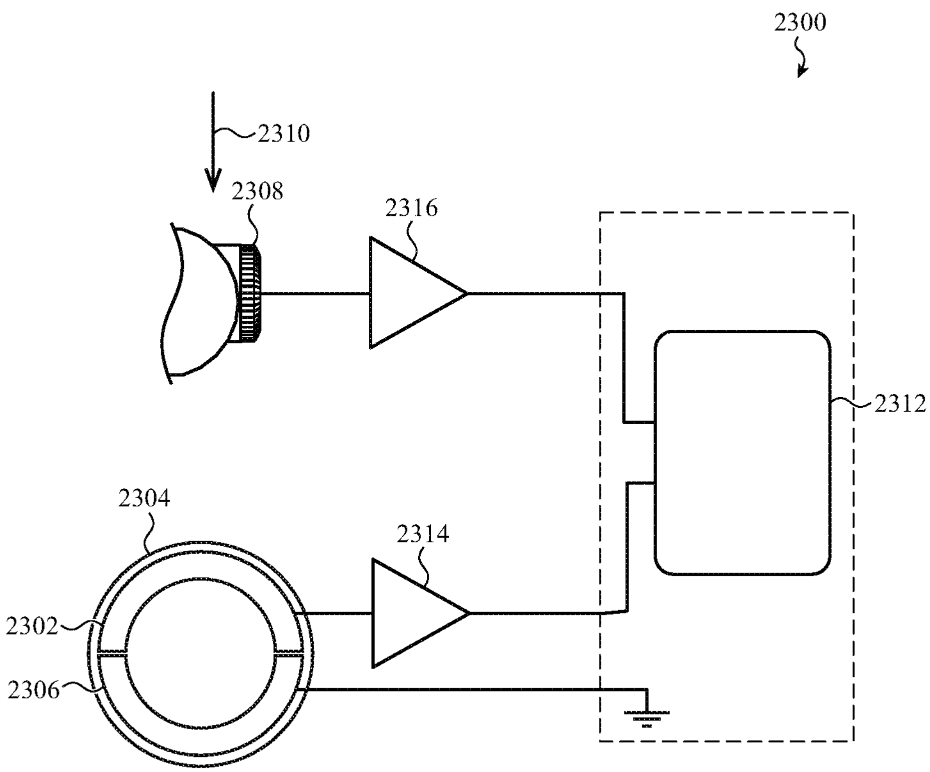

FIG. 23

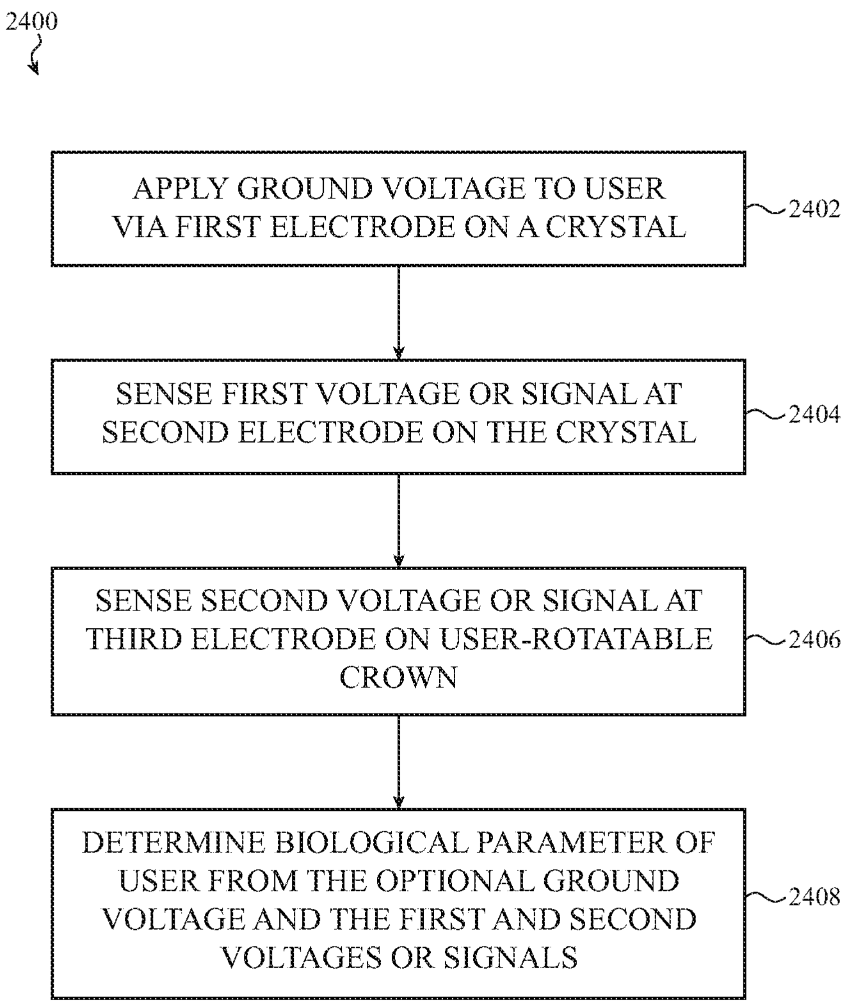
2400
APPLY GROUND VOLTAGE TO USER VIA FIRST ELECTRODE ON A CRYSTAL
2402
SENSE FIRST VOLTAGE OR SIGNAL AT SECOND ELECTRODE ON THE CRYSTAL
2404
SENSE SECOND VOLTAGE OR SIGNAL AT THIRD ELECTRODE ON USER-ROTATABLE CROWN
2406
DETERMINE BIOLOGICAL PARAMETER OF USER FROM THE OPTIONAL GROUND VOLTAGE AND THE FIRST AND SECOND VOLTAGES OR SIGNALS
2408

FIG. 24

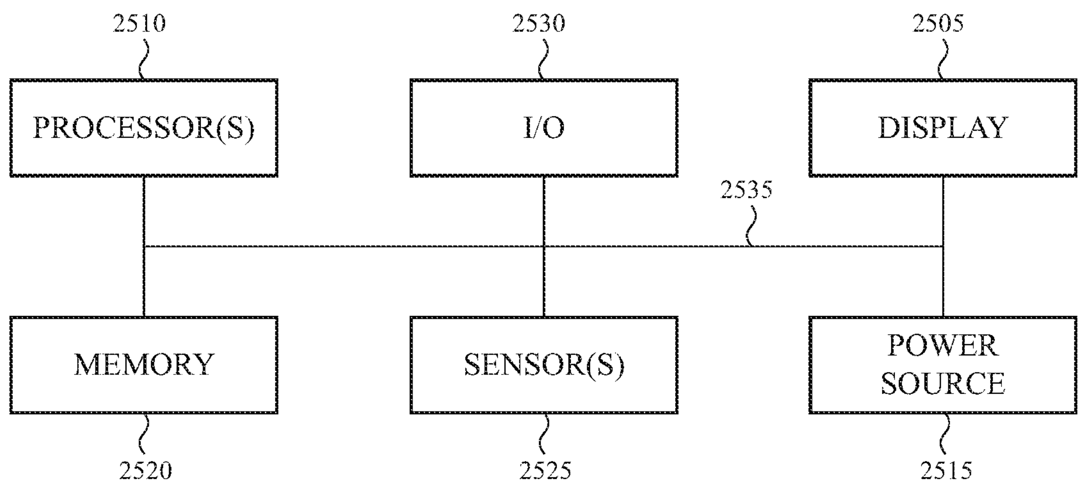
2510
PROCESSOR(S)
2530
I/O
2505
DISPLAY
2535
MEMORY
2520
SENSOR(S)
2525
POWER SOURCE
2515

FIG. 25

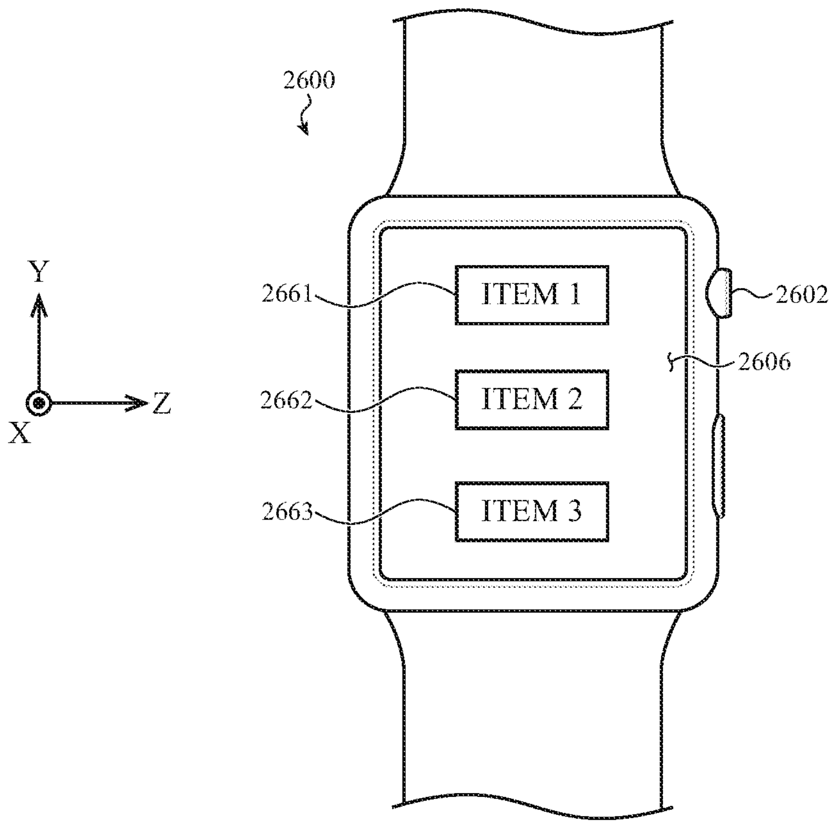

FIG. 26A

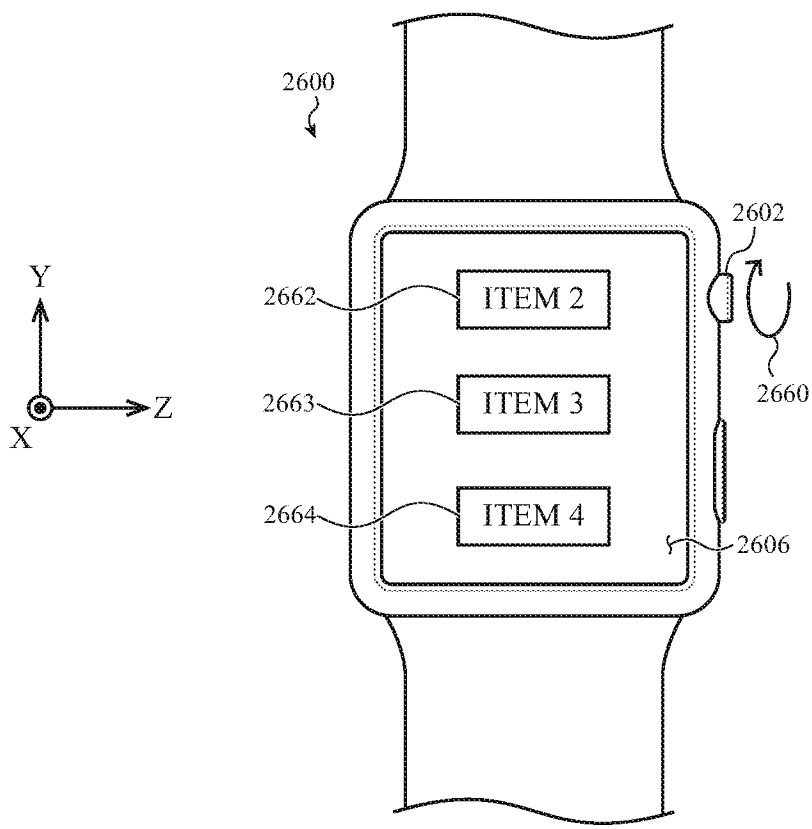

FIG. 26B

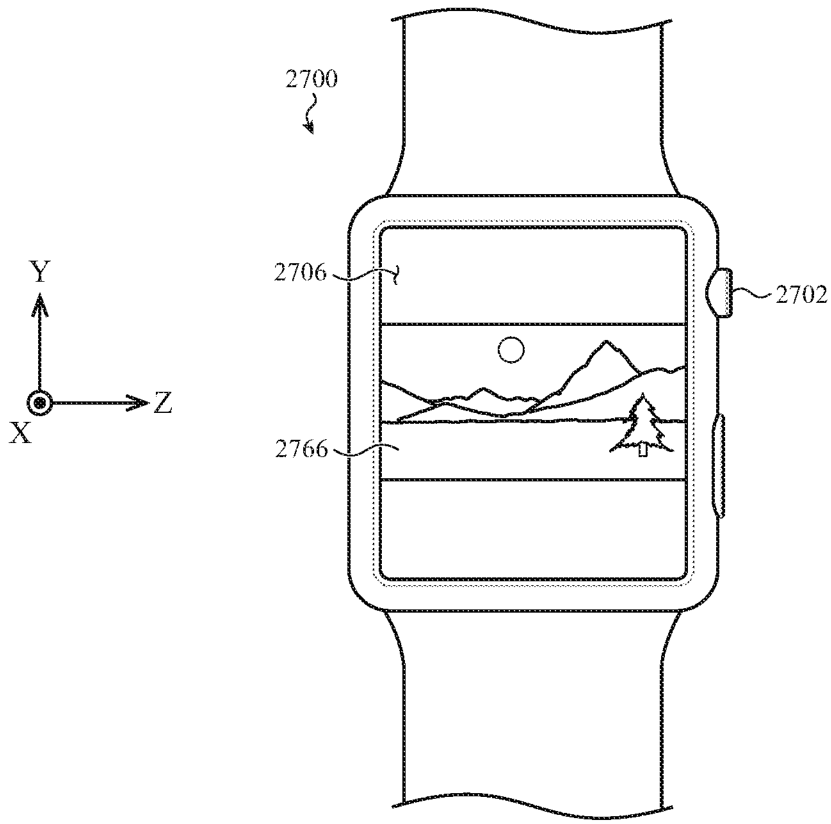

FIG. 27A

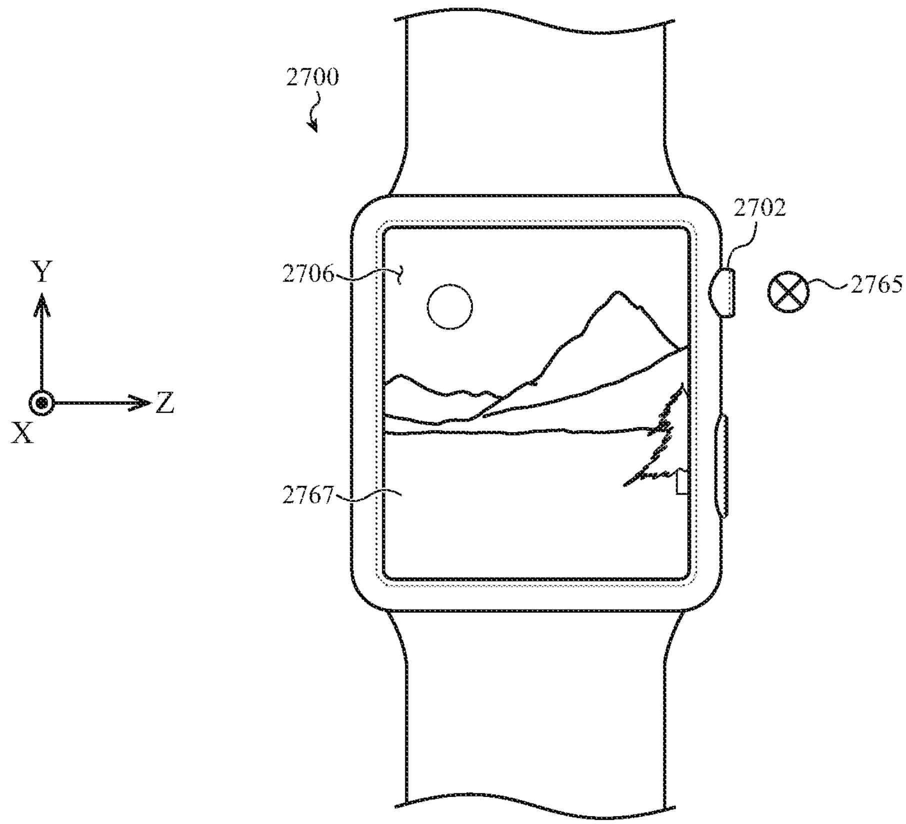

FIG. 27B

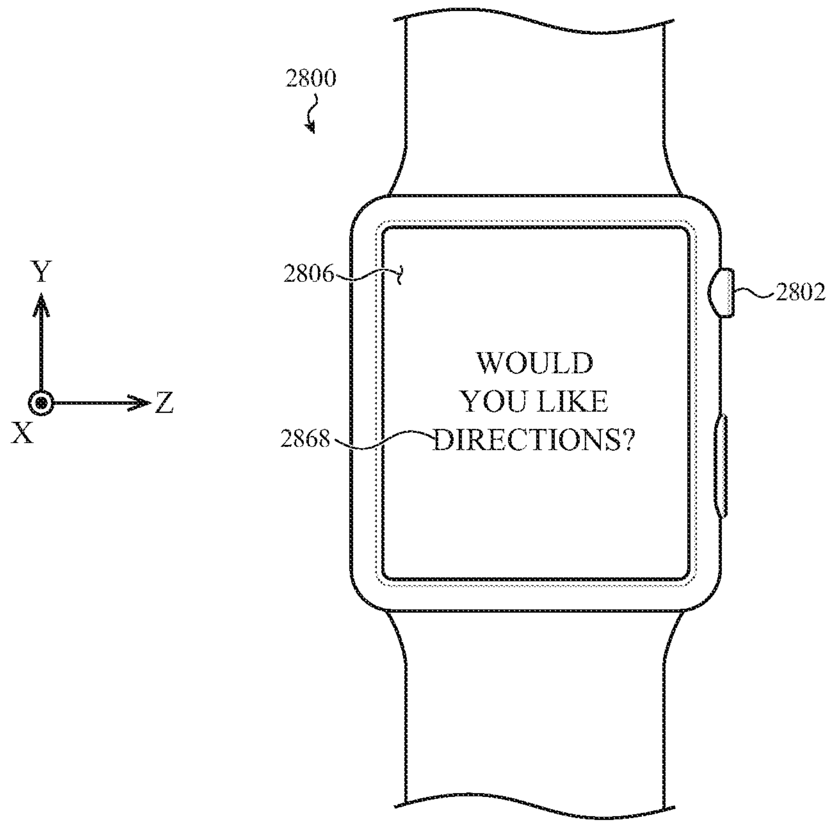

FIG. 28A

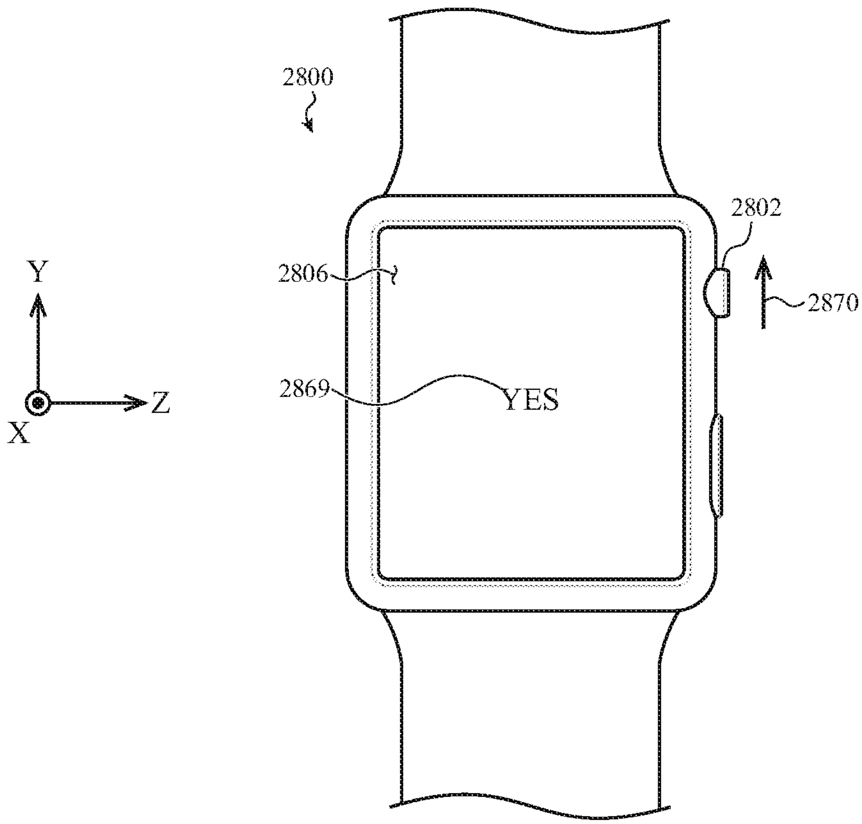

FIG. 28B

WEARABLE ELECTRONIC DEVICE WITH ELECTRODES FOR SENSING BIOLOGICAL PARAMETERS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 16/193,836, filed Nov. 16, 2018, and titled "Wearable Electronic Device with Electrodes for Sensing Biological Parameters," which is a continuation of U.S. patent application Ser. No. 16/118,282, filed Aug. 30, 2018, and titled "Wearable Electronic Device with Electrodes for Sensing Biological Parameters," which claims the benefit under 35 U.S.C. § 119(e) of U.S. Provisional Patent Application No. 62/554,196, filed Sep. 5, 2017, and titled "Wearable Device with Electrodes for Sensing Biological Parameters," and U.S. Provisional Patent Application No. 62/644,886, filed Mar. 19, 2018, and titled "Wearable Device with Electrodes for Sensing Biological Parameters," the contents of which are incorporated herein by reference as if fully disclosed herein.

FIELD

The described embodiments relate generally to an electronic watch or other wearable electronic device. More particularly, the described embodiments relate to techniques for providing, on a watch or other wearable electronic device, electrodes for sensing biological parameters. The electrodes may be variously provided on a surface of an optical component, crown, button, or housing member of the watch or other wearable electronic device.

BACKGROUND

A wearable electronic device may include a set of sensors for determining a set of biological parameters of a user that wears the wearable electronic device. Circuitry associated with the set of sensors may generate, for example, electrical signals or measurements corresponding to voltages at, forces applied to, or amounts of light incident on, the sensors. The various signals or measurements may be correlated to, or used to derive, various biological parameters of the user, such as a heart rate of the user.

SUMMARY

Embodiments of the systems, devices, methods, and apparatuses described in the present disclosure are directed to an electronic watch or other wearable electronic device having a set of electrodes that may be used to sense or determine biological parameters of a user that wears the wearable electronic device. The biological parameters may include, for example, an electrocardiogram (ECG) of the user.

One embodiment takes the form of an electronic watch, comprising: a housing; a crown comprising: a crown body; and a shaft connected to the crown body and passing through the housing; a carrier connected to the housing; a transparent cover connected to the housing; a touch-sensitive display at least partially within the housing and viewable through the transparent cover; a first electrode on the carrier; a second electrode on the crown body; and a processor within the housing and operationally connected to the first electrode and the second electrode; wherein: the first electrode is configured to measure a first voltage; the second electrode is configured to measure a second voltage; the processor is configured to determine an electrocardiogram using the first voltage and the second voltage; and the touch-sensitive display is configured to display the electrocardiogram.

Another embodiment takes the form of an electronic watch, comprising: a housing; a carrier attached to the housing; a first electrode on the carrier; a crown extending through the housing and configured to translate and rotate, comprising a second electrode; and a processor operable to determine a biological parameter of a user based on voltages measured at the first electrode and the second electrode; wherein: the voltages are measured while the user is in contact with the first electrode and the second electrode.

Yet another embodiment takes the form of a method for determining and displaying an electrocardiogram by an electronic watch, comprising: measuring a first voltage at a first electrode on a crown of the electronic watch; measuring a second voltage at a second electrode on a carrier of the electronic watch; determining, by a processor of the electronic watch, the electrocardiogram using the first voltage and the second voltage; and displaying the electrocardiogram on a display of the electronic watch.

In addition to the example aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the drawings and by study of the following description.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosure will be readily understood by the following detailed description in conjunction with the accompanying drawings, wherein like reference numerals designate like structural elements, and in which:

FIG. **1**A shows a functional block diagram of a wearable electronic device;

FIG. **1**B shows an example of an electronic device having a set of electrodes disposed thereon;

FIGS. **2**A-**2**C show an example of an electronic watch that incorporates a set of electrodes;

FIG. **3** shows another example of an electronic watch that incorporates a set of electrodes;

FIGS. **4**A-**4**D show an additional example of an electronic watch that incorporates a set of electrodes on a carrier;

FIGS. **5**A-**5**E illustrate an example of coatings that may be deposited on the interior and exterior surfaces of the carrier shown in FIGS. **4**A-**4**C;

FIG. **6** shows a cross-section of the carrier shown in FIG. **5**B;

FIG. **7** shows a cross-section of the carrier shown in FIGS. **5**C and **5**D;

FIG. **8** shows an example layer construction of an ITO-based electrode;

FIGS. **9**A-**9**C show alternative electrical connections between an electrode on an exterior surface of a carrier that forms part of a housing of an electronic device and an electrical contact interior to the electronic device;

FIGS. **10**A-**10**D show alternative carrier configurations, and alternative attachments or connections of carriers to other housing members of an electronic device;

FIG. **11**A is a cross-section of an example crown assembly;

FIG. **11**B is a cross-section of another example crown assembly;

FIGS. **12**A & **12**B show another example of a crown assembly;

FIGS. **13** & **14** show cross-sections of additional examples of crown assemblies;

FIGS. **15**-**22** show various examples of button assemblies;

FIG. **23** shows a schematic of an electronic device that may be used for acquiring an ECG or other biological parameter from a user of the electronic device;

FIG. **24** shows an example method of determining a biological parameter of a user wearing a watch or other wearable electronic device;

FIG. **25** shows a sample electrical block diagram of an electronic device such as a watch or other wearable electronic device;

FIG. **26**A illustrates a sample electronic watch displaying a list;

FIG. **26**B illustrates the sample electronic watch of FIG. **26**A, with an updated list in response to a crown input;

FIG. **27**A illustrates a sample electronic watch displaying a graphic;

FIG. **27**B illustrates the sample electronic watch of FIG. **27**A with the graphic updated in response to a crown input;

FIG. **28**A illustrates a sample electronic watch displaying a first graphic; and

FIG. **28**B illustrates the sample electronic watch of FIG. **28**A displaying a second graphic in response to a crown input.

The use of cross-hatching or shading in the accompanying figures is generally provided to clarify the boundaries between adjacent elements and also to facilitate legibility of the figures. Accordingly, neither the presence nor the absence of cross-hatching or shading conveys or indicates any preference or requirement for particular materials, material properties, element proportions, element dimensions, commonalities of similarly illustrated elements, or any other characteristic, attribute, or property for any element illustrated in the accompanying figures.

Additionally, it should be understood that the proportions and dimensions (either relative or absolute) of the various features and elements (and collections and groupings thereof) and the boundaries, separations, and positional relationships presented therebetween, are provided in the accompanying figures merely to facilitate an understanding of the various embodiments described herein and, accordingly, may not necessarily be presented or illustrated to scale, and are not intended to indicate any preference or requirement for an illustrated embodiment to the exclusion of embodiments described with reference thereto.

DETAILED DESCRIPTION

Reference will now be made in detail to representative embodiments illustrated in the accompanying drawings. It should be understood that the following description is not intended to limit the embodiments to one preferred embodiment. To the contrary, it is intended to cover alternatives, modifications, and equivalents as can be included within the spirit and scope of the described embodiments as defined by the appended claims.

The following disclosure relates to techniques for distributing a set of electrodes over a set of surfaces of a wearable electronic device, such as an electronic watch, and to techniques for electrically isolating the electrodes from other components of the device and/or mitigating effects of environmental factors when sensing voltages or signals indicative of one or more biological parameters of a user who is in contact with the electrodes, and to techniques for routing the voltages or signals within the device.

Embodiments further may take the form of an electronic watch, or other portable and/or wearable device, configured to detect an electrocardiogram ("ECG") of a person wearing or otherwise interacting with the electronic device. As one non-limiting example, a person may wear an electronic watch that has two external electrodes configured to be touched by the user. A first electrode may be placed on a rear surface of the watch and be in contact with skin on the wrist of the person. A second electrode may be defined by or on a crown of the watch and may be configured to be touched by a finger (or other body part) of the person.

FIG. **1**A shows a functional block diagram of a wearable electronic device **100**. In some examples, the device **100** may be an electronic watch or electronic health monitoring device. The wearable electronic device **100** may include one or more input devices **102**, one or more output devices **104**, and a processor **106**. Broadly, the input devices **102** may detect various types of input, and the output devices **104** may provide various types of output. The processor **106** may receive input signals from the input devices **102**, in response to inputs detected by the input devices. The processor **106** may interpret input signals received from one or more of the input devices **102** and transmit output signals to one or more of the output devices **104**. The output signals may cause the output devices **104** to provide one or more outputs. Detected input at one or more of the input devices **102** may be used to control one or more functions of the device **100**. In some cases, one or more of the output devices **104** may be configured to provide outputs that are dependent on, or manipulated in response to, the input detected by one or more of the input devices **102**. The outputs provided by one or more of the output devices **104** may also be responsive to, or initiated by, a program or application executed by the processor **106** and/or an associated companion device.

In various embodiments, the input devices **102** may include any suitable components for detecting inputs. Examples of input devices **102** include audio sensors (e.g., microphones), optical or visual sensors (e.g., cameras, visible light sensors, or invisible light sensors), proximity sensors, touch sensors, force sensors, mechanical devices (e.g., crowns, switches, buttons, or keys), vibration sensors, orientation sensors, motion sensors (e.g., accelerometers or velocity sensors), location sensors (e.g., global positioning system (GPS) devices), thermal sensors, communication devices (e.g., wired or wireless communication devices), resistive sensors, magnetic sensors, electroactive polymers (EAPs), strain gauges, electrodes, and so on, or some combination thereof. Each input device **102** may be configured to detect one or more particular types of input and provide a signal (e.g., an input signal) corresponding to the detected input. The signal may be provided, for example, to the processor **106**.

The output devices **104** may include any suitable components for providing outputs. Examples of output devices **104** include audio output devices (e.g., speakers), visual output devices (e.g., lights or displays), tactile output devices (e.g., haptic output devices), communication devices (e.g., wired or wireless communication devices), and so on, or some combination thereof. Each output device **104** may be configured to receive one or more signals (e.g., an output signal provided by the processor **106**) and provide an output corresponding to the signal.

The processor **106** may be operably coupled to the input devices **102** and the output devices **104**. The processor **106** may be adapted to exchange signals with the input devices **102** and the output devices **104**. For example, the processor **106** may receive an input signal from an input device **102** that corresponds to an input detected by the input device **102**. The processor **106** may interpret the received input signal to determine whether to provide and/or change one or more outputs in response to the input signal. The processor

106 may then send an output signal to one or more of the output devices 104, to provide and/or change outputs as appropriate. Examples of suitable processors are discussed in more detail below with respect to FIG. 25.

In some examples, the input devices 102 may include a set of electrodes. The electrodes may be disposed on one or more exterior surfaces of the device 100. The processor 106 may monitor for voltages or signals received on at least one of the electrodes. In some embodiments, one of the electrodes may be permanently or switchably coupled to a device ground. The electrodes may be used to provide an ECG function for the device 100. For example, a 2-lead ECG function may be provided when a user of the device 100 contacts first and second electrodes that receive signals from the user. As another example, a 3-lead ECG function may be provided when a user of the device 100 contacts first and second electrodes that receive signals from the user, and a third electrode that grounds the user to the device 100. In both the 2-lead and 3-lead ECG embodiments, the user may press the first electrode against a first part of their body and press the second electrode against a second part of their body. The third electrode may be pressed against the first or second body part, depending on where it is located on the device 100.

FIG. 1B shows an example of an electronic device 110 (here, an electronic watch) having a set of electrodes 112, 114 disposed thereon. The device 110 may be an example of the wearable electronic device described with reference to FIG. 1A, or may be an example of an electronic device that is not wearable. In some embodiments, the set of electrodes 112, 114 may be provided on one surface of the device 110. In other embodiments (as shown), the set of electrodes 112, 114 may include electrodes provided on different surfaces of the device 100, such as a first electrode 112 provided on a first surface 116 of the device 110, and a second electrode 114 provided on a second surface 118 of the device 110. Providing electrodes on different surfaces of a device may make it easier for a user to place different body parts in contact with different electrodes. For example, a user may place one or more of the electrodes (e.g., the first electrode 112) in contact with their wrist, and may touch another one or more of the electrodes (e.g., the second electrode 114) with a finger of their opposite hand. Alternatively, the user may press the electrodes 112, 114 against different parts of their body. A processor 120 of the device 110, or a processor remote from the device 110, may determine, from the voltages or signals (e.g., from stored digital samples or values representing the voltages or signals), the biological parameter(s) of the user. The biological parameter(s) may include, for example, an electrocardiogram (ECG) of the user, an indication of whether the user is experiencing atrial fibrillation, an indication of whether the user is experiencing premature atrial contraction or premature ventricular contraction, an indication of whether the user is experiencing a sinus arrhythmia, and so on.

In some embodiments, one or two thin film electrodes may be PVD deposited on an exterior surface of a structure that forms part of a housing of an electronic device. The surface may be any transparent, semi-transparent, translucent, or opaque surface made out of an amorphous solid, glass, a crystal or crystalline material (such as sapphire or zirconia), plastic, or the like. In the case of a watch (i.e., a type of electronic device), an additional electrode may be positioned on a user-rotatable crown of a watch body, on a button of the watch body, or on another surface of a housing that defines the watch body.

When an electrode is formed on a carrier that forms part of a housing of an electronic device, the electrode may be connected to an electrical contact within the electronic device by depositing the electrode material such that it wraps around an edge or perimeter of the carrier, and onto an interior surface of the carrier. The electrical contact may be on the interior surface of the carrier. In other embodiments, the electrode may be formed on the exterior surface of the carrier, and a thru-carrier via that is filled or coated with a conductive material may connect the electrode to an electrical contact within the electronic device. The carrier may be any appropriate structure that supports the electrodes, on which the electrodes are formed, or to which the electrodes are attached. In certain embodiments described herein, the carrier is an optically transparent material having a dome shape. It should be appreciated that the carrier may have different shapes (flat, stepped, parallelepiped, and so on) and may be made from different materials, including opaque materials.

Generally, the term "attached" means that two elements, objects, structures, or objects are separate but affixed or retained to one another, whether removably, as with an electronic device attached to a user by a band, or fixedly, as with two elements that are affixed to one another with a mechanical fastener not meant to be decoupled (a screw, bolt, or the like), by an adhesive, by plating or depositing one material on another (as with an electrode deposited on the carrier), and so on. The term "connected" means that two elements may be attached to one another, or may be two parts of a unitary whole (as with a shaft and crown body formed from the same material as a single piece). Thus, while two elements that are attached to one another are necessarily connected to one another, the reverse is not necessarily true. For example, two elements may be formed as a single piece or part and thus connected to one another, although they are not attached to one another.

When an electrode is provided on a crown of an electronic device, the crown may be conductive or have a conductive surface, and the conductive portion of the crown may be coupled to a conductive rotatable shaft that extends through an opening in a device housing. An end of the shaft interior to the housing, or a conductive shaft retainer interior to the housing, may be in mechanical and electrical contact with a spring-biased conductor that carries electrical signals between the shaft or shaft retainer and a circuit, thereby providing electrical communication between the crown and the circuit.

A processor of an electronic device (e.g., the processor 120) may be operable to determine a biological parameter of a user based on voltages at various electrodes (e.g., at the set of electrodes 112, 114). In some cases, the biological parameter may be an ECG of a user of the electronic device. For example, when a watch has a first electrode on an exterior surface of a carrier and a second electrode on a crown, the user's fastening of the watch to their wrist may place the first electrode in contact with skin on the user's wrist. To acquire an ECG, the user may touch a conductive portion of the crown with a finger on their opposite hand. For example, the carrier or housing of the watch may touch a wrist adjacent one hand, and the crown may be touched with a finger of the opposite hand. In some cases, the watch may have a third electrode, also on the exterior surface of the carrier, which grounds the user to the watch. The third electrode may be used to reject noise from ECG signals. The electrodes may be positioned on different surfaces, or different portions of surfaces, in various embodiments.

The electrode(s) on the exterior surface of the carrier may be positioned at the periphery of the carrier, or otherwise positioned to enable an optical sensor subsystem to emit and receive light through the carrier. The light may be emitted into, and reflected from, a user's skin to determine other biological parameters of the user, such as a heart rate, blood pressure, pulse, blood oxygenation, glucose level, and so on.

These and other embodiments are discussed with reference to FIGS. **1-25**. However, those skilled in the art will readily appreciate that the detailed description given herein with respect to these figures is for explanatory purposes only and should not be construed as limiting.

FIGS. **2**A-**2**C show an example of an electronic watch **200** that incorporates a set of electrodes. The watch **200** may be an example of the wearable electronic device **100** or **110** described with reference to FIG. **1**A or **1**B. The watch **200** may include a watch body **202** and a watch band **204**. The watch body **202** may include an input or selection device, such as a crown **210** or a button **212**. FIG. **2**A shows an isometric view of the watch body's front face. FIG. **2**B shows an example cross-section of the crown **210**. FIG. **2**C shows an isometric view of the watch body's rear face. In FIGS. **2**A & **2**C, only a portion of the watch band **204** is shown (i.e., only the portions of the watch band **204** that attach to the watch body **202**).

The watch body **202** may include a housing **206**. The housing **206** may include a front side housing member **206***a* that faces away from a user's skin when the watch **200** is worn by a user (see FIG. **2**A), and a back side housing member **206***b* (or rear cover) that faces toward the user's skin (see FIG. **2**C). Alternatively, the housing **206** may include a singular housing member, or more than two housing members. The one or more housing members may be metallic, plastic, ceramic, crystal, or other types of housing members (or may include combinations of such materials).

As shown in FIG. **2**A, a transparent cover **208** may be attached to a front side of the watch body **202** (i.e., facing away from a user's skin), over or within an opening in the housing **206**, and may protect a display positioned at least partially within the housing **206**. The display may be viewable by a user through the cover **208**. In some embodiments, the display may depict an ECG waveform of a person who is wearing or otherwise using the watch **200**. In some cases, the cover **208** may be part of a display stack, which display stack may include a touch sensing or force sensing capability. The display may be configured to depict a graphical output of the watch **200**, and a user may interact with the graphical output (e.g., using a finger or stylus that touches or hovers over the cover **208**, or using the crown **210** or button **212**). As one example, the user may select (or otherwise interact with) a graphic, icon, indicator, message, or the like (collectively, "graphic") presented on the display by touching or pressing on the display at the location of the graphic. In some embodiments, the user may receive confirmation of their selection by means of haptic output provided by the watch body **202** through the display or cover **208**. The exterior surface of the cover **208** may therefore function as a means for receiving input (i.e., function as an input device) and a means for providing output (i.e., function as an output device). The cover **208** may be attached to the housing **206** or part of the housing **206** (e.g., connected to the housing). In some embodiments, the cover **208** may be considered part of the housing **206** because it forms part of an outer shell that defines an interior volume (or houses internal components) of the watch body **202**. In some examples, the cover **208** may be or include a crystal, such as a sapphire crystal. Alternatively, the cover **208** may be formed of glass, plastic, or other materials.

The watch body **202** may include at least one input device or selection device, such as a crown **210**, scroll wheel, knob, dial, button **212**, or the like, which input device may be operated by a user of the watch **200**. In some embodiments, the crown **210**, scroll wheel, knob, dial, button **212**, or the like may be conductive, or have a conductive surface, and a signal route may be provided between the conductive portion of the crown **210**, scroll wheel, knob, dial, button **212**, or the like and a circuit (including a processor) within the watch body **202**.

The operation of determining and/or displaying a user's ECG may be initiated by rotating the crown **210**, translating the crown, tilting the crown, touching the crown, and so on. Likewise the operation of determining the ECG may be initiated by interacting with a touch-sensitive cover **208** or display of the electronic watch. As discussed above, the display may be partially or fully within the housing of the electronic watch.

Turning primarily to FIG. **2**B, it is shown that the housing **206** may include an opening through which a shaft **224** extends. A crown **210** may be connected to the shaft **224**, and may be accessible to a user exterior to the housing **206**. The crown **210** may be manipulated by a user to rotate or translate the shaft, as indicated by arrows **218** and **220**. Such manipulations are examples of crown inputs. The shaft may be mechanically, electrically, magnetically, and/or optically coupled to components within the housing **206**. In some embodiments, the crown **210** may be part of a crown assembly, as described with reference to FIG. **11**, **12**A, **12**B, **13**, or **14**.

A user's manipulation of the crown **210** (and thus the shaft **224**) may be used to manipulate or select various textual or graphical elements displayed by the watch **200**, to adjust a volume of a speaker, to turn the watch **200** on or off, and so on. In some embodiments, the crown **210** may be manipulated (e.g., rotated or pressed) to select or activate a health monitoring function of the watch **200** (e.g., an ECG or other heart monitoring function). For example, a user may rotate the crown to select an ECG application, and may press the crown to activate the ECG application (e.g., initiate determination and display of a wearer's ECG). Alternatively, a user's touch or press of the crown (or touch or press of the crown for a predetermined period of time) may activate the ECG application and cause a heart rhythm of the user to be displayed. As yet another example, the user may interact with the touch-sensitive display to select and/or activate the ECG application. By way of example, a user's activation of an ECG application is indicated by the watch's display of the ECG **222** in FIG. **2**A. Alternatively, the user's selection of an ECG application may be indicated by another graphic or text displayed by the watch **200**. Generally, the watch **200** (and specifically its display) may change from displaying some graphic or text to displaying the ECG **222** once the ECG (or its corresponding application, or function) is initiated, selected, or determined.

As shown in FIG. **2**B, the crown **210** may be connected to the shaft **224** (and may be unitary with the shaft), and the shaft **224** may extend through an opening in the housing **206**. In some embodiments, the shaft **224** may be separated from the housing **206** by a bushing or other component, or retained to the housing **206** by a retention mechanism. The shaft **224** may rotate or translate with respect to the housing **206**, as indicated by arrows **218** and **220**, thereby providing one or more crown inputs to a processor of the electronic

device **200**. A first sensor **226** within the housing **206** may sense aspects of shaft movement such as direction of rotation, speed of rotation, rotational acceleration, or angular position of the shaft **224**. In some embodiments, the first sensor **226** may be an optical sensor positioned adjacent the shaft **224**, such that light **227** is emitted onto, and reflected from, the shaft **224**. Light **227** may be reflected from the shaft by a pattern of surface features (such as scallops, grooves, indentation, projections, or the like) or by byproducts of machining the shaft, such as bumps, scratches, irregularities, and so on. The pattern and speed of light **227** reflected onto the optical sensor **226** maybe used to determine a direction and/or speed of rotation of the shaft **224**. In other embodiments, different sensors may be used to detection direction and/or speed of rotation of the shaft **224**, including mechanical sensors, electrical sensors, capacitive sensors, brush contacts, magnetic sensors, and so on.

A second sensor **228** within the housing **206** may sense aspects of shaft movement such as translation or direction of translation. In some embodiments, the second sensor **228** may be a tactile switch, optical sensor, magnetic sensor, capacitive sensor or the like positioned at an end of the shaft **224**.

A third sensor **230** within the housing **206** may sense when a user is touching the crown **210**, or may sense signals (e.g., a heart rhythm) received by the crown **210** when a user touches the crown **210**. In some embodiments, the third sensor **230** may be electrically coupled to the crown **210** or shaft **224**. In some cases, the sensors **226**, **228**, **230** may be provide signals or information to the processor **214**, or may be partly or wholly integrated with the processor **214** or other components of the watch **200**. In some embodiments, two or more of the sensors **226**, **228**, **230** may be combined into a multipurpose sensor. In some embodiments, one or more of the sensors **226**, **228**, **230** may not be provided. In some embodiments, the functions of one of the sensors **226**, **228**, **230** may be distributed among multiple sensors, or additional crown sensors may be provided.

Any or all of the first sensor **226**, second sensor **228**, and third sensor **230** may be attached to or otherwise supported by one or more internal supports **232**, as shown in FIG. **2**B.

Turning primarily to FIG. **2**C, the housing **206** may include structures for attaching the watch band **204** to the watch body **202**. In some cases, the structures may include elongate recesses or openings through which ends of the watch band **204** may be inserted and attached to the watch body **202**. In other cases (not shown), the structures may include indents (e.g., dimples or depressions) in the housing **206**, which indents may receive ends of spring pins that are attached to or threaded through ends of a watch band to attach the watch band to the watch body **202**.

The watch band **204** may be used to secure the watch **200** to a user, another device, a retaining mechanism, and so on.

As previously mentioned, the watch **200** may include a set of electrodes. The set of electrodes may be configured, in some cases, as described with reference to FIG. **1**A or **1**B. The set of electrodes may be used by a processor **214** that is internal to the watch body **202**, to sense biological parameters (e.g., an ECG) of a person who wears the watch **200** and presses the electrodes against their skin. In some embodiments, the set of electrodes may include a rear-facing electrode **216** on the back of the watch body **202** (e.g., on the back side housing member **206***b*). The set of electrodes may also include an electrode on the crown **210** and/or an electrode on the button **212**.

The rear-facing electrode **216** may be formed (e.g., printed, plated, or otherwise deposited) on the back side housing member **206***b*. If the back side housing member **206***b* is non-conductive, the rear-facing electrode **216** may be formed directly on the back side housing member **206***b* and connected to circuitry internal to the watch body **202** (e.g., the processor **214**) by, for example, conductive vias formed through the back side housing member **206***b*. If the back side housing member **206***b* is conductive, the rear-facing electrode **216** may be separated from the back side housing member **206***b* by an insulator or insulating layer, and conductive vias formed through the back side housing member **206***b* may likewise be insulated from the back side housing member **206***b*. Alternatively, the back side housing member **206***b* may have an opening to which the rear-facing electrode **216** is mated. In some embodiments, the opening may define a ledge in the back side housing member **206***b*, and the rear-facing electrode **216** may rest on the ledge (and in some cases may be separated from the back side housing member **206***b* by an insulator (e.g., a seal) or an insulating layer).

The electrode(s) on the crown **210** or button **212** may be conductive surfaces of the crown **210** or button **212**. In some cases, the crown **210** or button **212** may be conductive over its entire exterior surface. In other cases, the crown **210** or button **212** may have conductive portions (e.g., cores or inserts). When the front side housing member **206***a* is conductive, the crown **210** or button **212** (or the conductive components thereof) may be insulated from the front side housing member **206***a* by an insulator (e.g., a set of seals, non-conductive coatings, and so on).

In some embodiments, one of the crown **210** or button **212** may have an electrode thereon, and a user wearing the watch **200** on one of their wrists may touch the electrode on the crown **210** or button **212** with a finger of their opposite hand. The processor **214** may then use the electrodes to acquire an ECG for the user. In other embodiments, both the crown **210** and the button **212** may have an electrode thereon, and a user wearing the watch **200** on one of their wrists may touch the electrodes on the crown **210** and button **212** with a finger of their opposite hand. In still other embodiments, the entirety of the back side housing member **206***b* (or even the entirety of the housing **206**) may be an electrode. In these latter embodiments, electrical isolation may be provided between the housing **206** and the crown **210** and/or between the housing **206** and the button **212**.

In some examples, the watch **200** may lack the display, the crown **210**, or the button **212**. For example, the watch **200** may include an audio input or output interface, a touch input interface, a haptic (force) input or output interface, or other input or output interface that does not require the display, crown **210**, or button **212**. The watch **200** may also include the afore-mentioned input or output interfaces in addition to the display, crown **210**, or button **212**. When the watch **200** lacks the display, the front face of the watch **200** may be covered by the cover **208**, or by a metallic or other type of housing member (e.g., the opening for the cover **208** may not exist, and the front side housing member **206***a* may extend over the area defined by the cover **208**). In these embodiments, the electrode(s) on the crown **210** or button **212** may be replaced by (or supplemented with) an electrode on the front face of the watch body **202**. A user may touch the front-facing electrode with a finger, similarly to how they would touch an electrode on the crown **210** and/or button **212**. Alternatively, a user could place the front-facing electrode in contact with, for example, an opposite wrist, part of their leg, or their torso or forehead.

In some embodiments, the watch **200** may lack the rear-facing electrode **216**, and each of the crown **210** and the

button **212** may have a conductive surface that serves as an electrode. In these embodiments, the watch **200** may need to be removed from a user's wrist to enable the user to press different parts of their body against the crown and button electrodes. In some embodiments, the crown **210** or the button **212** may be moved to an opposite side of the watch body **202**, thereby increasing the separation between the crown **210** and the button **212** and making it easier for a user to press different parts of their body against the crown and button electrodes.

Other electronic devices that may incorporate a set of electrodes include other wearable electronic devices, other timekeeping devices, other health monitoring or fitness devices, other portable computing devices, mobile phones (including smart phones), tablet computing devices, digital media players, or the like.

Because the voltages or signals provided at, propagated from, or monitored at the various electrodes of a set electrodes may be low voltage or have low amplitudes, the materials, positions, electrical connections to, and electrical routing paths for the set of electrodes can have a significant impact on a processor's ability to discern useful signals representing an ECG or other biological parameter of a person wearing the watch **200** or a similar device (e.g., one of the other watches or electronic devices described herein). The materials, positions, electrical connections to, and electrical routing paths for the set of electrodes can determine how well the electrodes receive voltages/signals from the person's skin (e.g., a signal-to-noise ratio (SNR) of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the electrodes and internal components of the watch **200** (e.g., a voltage/signal propagation SNR); and how well the electrodes operate in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. Techniques described in the present disclosure may improve the usability of a set of electrodes under some or all of these conditions.

FIG. **3** shows another example of an electronic watch **300** that incorporates a set of electrodes. The watch **300** may be an example of the wearable electronic device **100** or **110** described with reference to FIG. **1** or **1**B, and may include many of the components of the watch **200** described with reference to FIGS. **2**A-**2**C. The watch **300** may include a watch body **202** and a watch band **204**. FIG. **3** shows an isometric view of the watch body's rear face. Only a portion of the watch band **204** is shown (i.e., only the portions of the watch band **204** that attach to the watch body **202**).

The watch **300** in FIG. **3** differs from the watch **200** of prior figures in that it has a different set of internal components, a different back side housing member **302**, and a different set of elements that are provided or exposed on the back side housing member **302**. For example, the watch **300** may include a sensor subsystem that includes both electrical and optical components. The electrical components may include one or more electrodes **304**, **306** formed on the back side housing member **302**. In some cases, each of the electrodes **304**, **306** may have a circular shape and may be PVD deposited on the back side housing member **302**. Alternatively, only one, or more than two electrodes may be formed on the back side housing member **302**, or the electrodes **304**, **306** may be positioned over (or inset into) openings in the back side housing member **302**.

The optical components of the sensor system may include a set of one or more windows **308**, **310**, **312**, **314** in the back side housing member **302**. Each of the windows **308**, **310**, **312**, **314** may pass at least one wavelength of light. In some cases, each of the windows **308**, **310**, **312**, **314** may have a semicircular shape. The windows may alternatively have other shapes. The windows may be formed of crystal, glass, plastic or another material that passes at least one wavelength of light emitted or received by the sensor subsystem.

In some embodiments, the back side housing member **302** may be or include a transparent cover (e.g., a cover including a crystal, such as a sapphire crystal, or glass, or plastic, or the like), and may be substantially flat or planar (as shown) or may be curved or otherwise non-planar. A mask (e.g., an ink mask and/or dark mask) may be applied to the transparent cover to define the windows **308**, **310**, **312**, **314**. The electrodes **304**, **306** may be formed on top of the mask or over openings in the mask.

In some embodiments, the back side housing member **302** may be an opaque substrate, such as a metal or plastic substrate, and one or more transparent windows **308**, **310**, **312**, **314** may be fitted to openings in the substrate. The transparent windows may be fitted to the openings internally to (or externally from) the watch body **202**. The electrodes **304**, **306** may be fitted to additional openings that enable the electrodes **304**, **306** to protrude outward from the external surface of the back side housing member **302**, or the electrodes **304**, **306** may be formed on the surface of the back side housing member **302** and the electrically connected to components internal to the watch body **202** by conductive vias or other elements formed through the surface of the back side housing member **302**.

By way of example, FIG. **3** shows the electrodes **304**, **306** aligned along a first axis that divides the back side housing member **302** into two halves, and shows the windows **308**, **310**, **312**, **314** aligned along a second axis, perpendicular to the first axis, that divides the back side housing member **302** into a different two halves. In this manner, the electrodes **304**, **306** and windows **308**, **310**, **312**, **314** may form four circular areas on the exterior surface of the back side housing member **302**, with the circular areas that contain the windows **308**, **310**, **312**, **314** appearing bifurcated.

In use, each pair of windows **308**/**310**, **312**/**314** forming a circular area may include a first window under which one or more light emitters are positioned, and a second window under which one or more light receivers are positioned, with an optional set of one or more light blocking walls positioned between the one or more light emitters and the one or more light receivers (or around the light emitter(s), or around the light receiver(s)).

FIGS. **4**A-**4**D show an additional example of an electronic watch **400** that incorporates a set of electrodes. The watch **400** may be an example of the wearable electronic device **100** or **110** described with reference to FIG. **1**A or **1**B, and may include many of the components of the watch **200** described with reference to FIGS. **2**A-**2**C. The watch **400** may include a watch body **202** and a watch band **204**. FIG. **4**A shows an isometric view of the watch body's rear face. Only a portion of the watch band **204** is shown (i.e., only the portions of the watch band **204** that attach to the watch body **202**).

Similarly to the watch **300** described with reference to FIG. **3**, the watch **400** may include a sensor subsystem that includes both electrical and optical components. However, the electrical and optical components of the watch **400** may be arranged differently than the electrical and optical components of the watch **300**.

Referring primarily to FIG. **4**A, a light-transmissive element such as a carrier **404** (e.g., a rear-facing or skin-facing carrier) may be coupled to or otherwise attached to a back side housing member **402** of the watch **400**, and in some

cases may be considered to form a part of the housing **206** of the watch body **202**. The carrier **404** may have a first surface **406** that is interior to the watch body **202** (see FIG. **4**C) and a second surface **408** that is exterior to the watch body **202** (see FIG. **4**A). The carrier **404** may be dome-shaped or otherwise non-planar, as shown in FIGS. **4**A-**4**C, such that the second surface **408** protrudes or extends away from a back member **402** of the watch **400**. This is best illustrated in FIGS. **4**B and **4**C.

By way of example, the carrier **404** is shown as having a round perimeter and fitted to a round opening in the back side housing member **402**. In other examples, the carrier **404** may have a perimeter that is square, oval, or some other shape. Similarly, the opening in the back side housing member **402** may be square, oval, or some other shape. The perimeter of the carrier **204** and the perimeter of the opening need not have the same size or shape (e.g., the perimeter of the opening in the back side housing member **402** may be smaller or differently shaped than the perimeter of the carrier **404**). In some examples, the carrier **404** may be a sapphire crystal. Alternatively, the carrier **404** may be formed from (or replaced by) a light-transmissive element formed of glass, plastic, or another material. The carrier **404** may be transparent to all wavelengths of light or just some wavelengths (and even one wavelength) of light.

The exterior surface **408** of the carrier **404** may have a set of electrodes (e.g., first and second (or rear-facing) electrodes **412**, **414**) thereon, although in some embodiments a single electrode or more than two electrodes may be used. In some embodiments, the electrodes **412**, **414** may be PVD deposited on the carrier **404**. Example constructions of the electrodes **412**, **414** and masks **422** are described with reference to FIGS. **5**A-**5**E, **6**-**8**, **9**A-**9**C, & **10**A-**10**D. In some embodiments, the electrodes **412**, **414** may be opaque. In other examples, the electrodes **412**, **414** may be formed of a transparent material, as described with reference to FIG. **6**, and the optical sensor subsystem **416** may transmit/receive light through the electrodes **412**, **414**. The optical sensor subsyste4m **416** may be, for example, an optical heart rate sensor.

In some cases, the first and second electrodes **412**, **414** may be arc-shaped (e.g., semi-circle-shaped), and may be positioned around a central opening **418** and concentric ring of openings **420** formed in the masks **422**. The first and second electrodes **412**, **414** may extend to the edge of the carrier **404**, and in some cases may wrap around the perimeter of the carrier **404** to the interior surface **406** of the carrier **404**, or be connected to conductive vias formed in the carrier **404**, or otherwise be electrically connected to elements within the watch body **202** that receive a signal sensed by one or both of the first and second electrodes **412**, **414**. In some cases, the first and second electrodes **412**, **414** may be electrically insulated from the back side housing member **402** (e.g., by a non-conductive gasket or adhesive), or the back side housing member **402** may be non-conductive. In some cases, the first and second electrodes **412**, **414** may be formed of, or include, stainless steel (SUS) or diamond like carbon (DLC).

The electrodes **412**, **414** may be positioned (e.g., at the periphery of the carrier **404** or in other locations) so as not to interfere with optical communication between an optical sensor subsystem **416** interior to the watch body **202** (see FIG. **4**C) and a medium (e.g., skin) exterior to the watch body **202**. The optical communication may occur through the carrier **404**, and in some cases may occur through a number of openings **418**, **420** formed in one or more masks **422** applied to the carrier **404**. The optical sensing subsystem is discussed in more detail, below.

FIG. **4**B shows an elevation of the watch body **202** shown in FIG. **4**A. The exterior of the watch body **202** is defined primarily by the housing **206**, the transparent cover **208**, and the carrier **404**. The carrier **404** supports the rear-facing electrodes **412**, **414** (e.g., as described with reference to FIGS. **4**A, **4**C, **5**C, **5**D, **5**E, **6**-**8**, **9**A-**9**C, & **10**A-**10**D). The element **430** may represent the crown **210** or button **212**. For ease of explanation, it is noted that the positions of the electrodes **412**, **414** on the carrier **404** have been rotated 90 degrees with respect to their positions in FIGS. **4**A & **4**C.

The watch body **202** may be abutted to a user's wrist **432** or other body part, and may be adhered to the user by the watch band **204** or another element. When abutted to a user's wrist **432**, the electrodes **412**, **414** on the carrier **404** may contact the user's skin. The user may touch a conductive portion of the element **430** with a finger **434**. The user may touch the element **430** in various ways, depending on where the element **430** is conductive, and depending on the user's preference. In some cases, the user may touch the element **430** while also touching their wrist **432**. However, high skin-to-skin impedance tends to reduce the likelihood that signals will travel from the electrodes **412**, **414**, through their wrist **432** to their finger **434**, and subsequently to the element **430** (or vice versa). In some cases, the user may touch the element **430** while also touching the housing **206**, which may be okay if the housing **206** is not conductive.

FIG. **4**C shows an exploded view of components that may be attached to the interior surface **406** of the carrier **404** shown in FIGS. **4**A & **4**B. When the watch body **202** shown in FIGS. **4**A & **4**B is assembled, the components shown in FIG. **4**C may reside within the housing **206**. By way of example, FIG. **4**C shows the components in relation to the back side housing member **402** (i.e., in relation to a skin-facing housing member).

In some cases, the interior components shown in FIG. **4**C may be attached to (and in some cases directly on) the interior surface **406** of the carrier **404**. The interior surface **406** may sometimes be referred to as a first surface of the carrier **404**. The components attached to the carrier **404** may include a lens **436**, a light filter **438**, one or more adhesives **440**, **442**, the optical sensor subsystem **416**, circuitry or a processing subsystem **444**, a magnet **446**, or a magnetic shield **448**.

The lens **436** may abut, be attached to (and optionally, directly on), or be formed on the first or interior surface **406** of the carrier **404**. By way of example, the lens **436** is aligned with the center of the carrier **404**. In some cases, the interior or exterior surface **406**, **408** of the carrier **404** may have a mask **422** thereon (e.g., an ink mask or dark mask, and in some cases a plurality of masks). The mask **422** may define an opening **418** (e.g., a first opening or central opening) that allows light of at least one wavelength to pass through the carrier **404**, and the lens **436** may be aligned with the opening **418**. In some cases, the lens **436** may be or include a Fresnel lens, a spherical lens, a diffuser film, or the like.

In some cases, the light filter **438** may include one or more segments **450**, and each segment **450** may be attached to (e.g., laminated to) the interior surface **406** of the carrier **404** and positioned on the interior surface (e.g., adjacent or around the lens **436**) to prevent a set of one or more light receivers of the optical sensor subsystem **416** from receiving a portion of the light that is emitted by a set of one or more light emitters of the optical sensor subsystem **416**. The set of light emitters and set of light receivers are not shown in FIG.

4C, and may be attached to an underside of the optical sensor subsystem **416**. When the carrier **404** includes the mask **422**, the mask **422** may further define a second opening **420***a*, or a set of openings **420** including the second opening **420***a*. The second opening **420***a* or set of openings **420** may be positioned adjacent or around the first opening **418**. In these embodiments, the segments **450** of the light filter **438** (or a light filter ring or other light filter configuration) may be aligned with (e.g., may cover) each of the openings in the set of openings **420**.

As an example, FIG. **4**C shows a mask **422** that defines a set of eight radial openings **420** around a central opening **418**. Each segment **450** of the light filter **438** may block (e.g., absorb) a portion of light emitted by a set of light emitters that is attached to the optical sensor subsystem **416**, which portion of light reflects from a surface too close to (or within) the carrier **404** (e.g., the exterior surface **408** of the carrier **404**, imperfections within the carrier **404**, or a medium too close to the carrier **404**), such that the reflected light is not useful in a sensing operation for which the optical sensor subsystem **416** is designed. For example, when the optical sensor subsystem **416** is configured to determine a biological parameter of a user, light reflected from the carrier **404**, or from the outer layer of skin of the user, may not have any relation to the biological parameter determined and may not be useful. Accordingly, the filter may be configured to filter out light frequencies associated with light reflected from the carrier and/or a skin surface, allowing light reflected from deeper skin layers, blood vessels, and the like to be received by the receiver(s). In some examples, the light filter **438** or segments **450** thereof may include at least one of a light control film, a light polarizer, an anti-reflective film, a reflective film, or a light absorber. Accordingly and as one non-limiting example, the optical sensor subsystem **416** may act as an optical heart rate detector.

In some embodiments, the mask **422** may represent multiple masks, and different masks may allow different wavelengths of light to pass through the carrier **404**, as described for example with reference to FIGS. **5**A-**5**E & **6**.

The optical sensor subsystem **416** may include a substrate **452** on which the set of one or more light emitters (e.g., LEDs) and the set of one or more light receivers (e.g., photodetectors, such as photodiodes) are attached. The light emitter(s) and light receiver(s) may be attached or positioned on the substrate **452** to emit and receive light through the carrier **404**. The sensor subsystem **416** may be attached to the carrier **404** by one or more adhesives **440**/**442**, such as pressure sensitive adhesives (PSAs) or heat-activated films (HAFs). In some cases, the set of light emitters may be centrally attached on the substrate **452**, and a first wall may be attached to (e.g., formed on or bonded to) an underside of the substrate **452** surrounding the set of light emitters. The first wall may be attached to the interior surface **406** of the carrier **404** using a first adhesive **440**. The set of light receivers may be attached on the substrate **452** around the set of light emitters, between the first wall and a second wall attached to (e.g., formed on or bonded to) the underside of the substrate **452**. The second wall may be attached to the interior surface **406** of the carrier **404** using a second ring of adhesive **442**.

The substrate **452** of the optical sensor subsystem **416** may include various contacts, pads, traces, or other conductive structures **454** that enable the processing subsystem **444** to be electrically coupled to the set of light emitters and set of light receivers of the optical sensor subsystem **416**. The processing subsystem **444** may include a substrate **456** (e.g., a printed circuit board (PCB)) that is attached to the optical

sensor subsystem **416**, and thereby to the carrier **404**, via the conductive structures **454** and/or additional adhesive between the substrates **452**, **456** of the optical sensor subsystem **416** and the processing subsystem **444**. The substrates **452**, **456** may also or alternatively be connected using mechanical fasteners (e.g., screws). The processing subsystem **444** may activate the light emitters and light receivers to perform a sensor function (e.g., to determine a heart rate). In some cases, the processing subsystem **444** may be attached to another structure within the watch body, and may be electrically connected to the conductive structures **454** of the optical sensor subsystem **416** by a flex circuit or other conductors.

In some embodiments, the substrate **456** of the processing subsystem **444** may have a hole **458** therein, and the magnet **446** may be aligned with the hole **458** and abutted to (or attached to) the substrate **452**. In some cases, the magnet **446** may be adhesively bonded to the substrate **452** of the optical sensor subsystem **416**. The magnet **446** may inductively couple to a battery charger used for charging a battery included within the watch body, which battery may power components of the watch including the components of the optical sensor subsystem **416** and the processing subsystem **444**.

The magnetic shield **448** may abut (or be attached to) the magnet **446**. In some cases, the magnetic shield **448** may be adhesively bonded to the magnet **446**. The magnetic shield **448** may direct magnetic flux associated with the magnet **446** toward and out the carrier **404** to improve inductive battery charging performance for a battery included within the watch body **202**.

Direct or indirect connection of the components shown in FIG. **4**C to the interior surface **406** of the carrier **404** can reduce the height of the components when stacked.

FIG. **4**D shows the sensor subsystem **416** attached to the carrier **404** shown in FIGS. **4**A-**4**C. FIG. **4**B also shows a flex circuit **460**, surrounding the sensor subsystem **416**, which may provide electrical connections between the electrodes **412**, **414** and the sensor subsystem **416** while also providing a ground that operates as an electrical noise mitigation barrier (or E-shield) between the sensor subsystem **416** and the electrodes **412**, **414**. The electrodes **412**, **414** may be connected to the electrical contacts **462**, **464**, which electrical contacts **462**, **464** are on the interior surface of the carrier **404** and connected to both traces in the flex circuit **460** and the electrodes **412**, **414**. Traces in the flex circuit **460** may be connected to the electrical contacts **462**, **464** via a conductive epoxy, and may connect the electrical contacts **462**, **464** to the sensor subsystem **416**. A processor may be part of the sensor subsystem **416**, and the processor may be connected to another processor or other circuitry via a flex circuit **466**.

FIGS. **5**A-**5**E illustrate an example of coatings that may be deposited on the interior and exterior surfaces of the carrier **404** shown in FIGS. **4**A-**4**C. As shown in FIG. **5**A, a first mask **500** (e.g., a first ink mask) that is opaque to infrared (IR) and visible light may be deposited (e.g., PVD deposited) on the interior surface **406** of the carrier **404**. In some examples, the first mask **500** may include an inner ring **500***a* and an outer ring **500***b* that define a central first opening **418** and a concentric second opening **506** (i.e., a second opening **506** that is concentric with the first opening **418**). The central first opening **418** may be positioned over light emitters of the optical sensor subsystem **416** described with reference to FIG. **4**C (and over the optional lens **436**), and the concentric second opening **506** may be positioned above light receivers of the sensor subsystem **416**. The inner

ring **500***a* of the first mask may prevent the light receivers from receiving light that is unlikely to have passed through a user's skin after passing through the central first opening **418**. The outer ring **500***b* of the first mask **500** may in some cases be provided for cosmetic reasons, and in some cases may not be provided.

FIG. **5**B shows a second mask **508** (e.g., a second ink mask) that is opaque to visible light but transparent to IR light. The second mask **508** may be deposited (e.g., PVD deposited) on the interior surface **406** of the carrier **404**. The second mask **508** may be deposited on the carrier **404** over the concentric second opening **506** in the first mask **500**, and may overlap the inner and outer rings **500***a*, **500***b* of the first mask, as shown in FIG. **6**. The second mask **508** may define a plurality of visible light openings **420** above respective light receivers of the optical sensor subsystem **416**, while allowing IR light to pass through the entirety of the concentric second opening **506**. This may increase the amount of IR light received by the light receivers. The second mask **508** may also define an optional opening above a condensation detector **512**. In some cases, the second mask **508** may look visually similar to the first mask **500** (e.g., both masks may be dark masks, such that it may be impossible or difficult for a user to visually distinguish the first and second masks **500**, **508**).

FIGS. **5**C and **5**D show an example of PVD deposited first and second electrodes **514***a*, **514***b* on the interior and exterior surfaces **406**, **408** of the carrier **404**. The first and second electrodes **412**, **414** may be arc-shaped and positioned at the periphery of the carrier **404**. The first and second electrodes **412**, **414** may be sized based on factors such as: providing a sufficient area to provide good electrical contact between the electrodes **412**, **414** and skin (which may improve electrical sensor efficiency); providing electrodes **412**, **414** of a size that do not substantially interfere with an antenna or other electrical structures of a device (which may improve wireless communication efficiency); or providing electrodes **412**, **414** positioned to allow optical communication through the carrier **404** (which may improve optical communication efficiency). The first and second electrodes **412**, **414** may be separated from one another by a pair of gaps **518***a*, **518***b*.

The first and second electrodes **412**, **414** may be deposited on both the interior and exterior surfaces **406**, **408** of the carrier **404** and may wrap around the edge (or perimeter) of the carrier **404**. The material used to form the first and second electrodes **412**, **414** may be patterned to form electrical contacts **520***a*, **520***b* (e.g., tabs) on the interior surface **406** of the carrier **404**. The first and second electrodes **412**, **414** may overlap the first mask **500** (or outer ring **500***b* of the first mask) on the interior surface **406** of the carrier **404**, such that the first mask **500** is positioned between the first and second electrodes **412**, **414** and the interior surface **406** of the carrier **404**. Thus, the material used to form the electrodes **412**, **414** may need to have properties that enable the material to adhere to a carrier surface (e.g., a sapphire surface) and a mask (e.g., an ink mask). The material or materials used to form the electrodes **412**, **414** may also have properties, singularly or in combination, such as: a low impedance and good conductivity (e.g., a low DC resistance); a low electrode-to-skin impedance; a high hardness to reduce scratching of the electrodes **412**, **414**; a higher elastic modulus than the carrier **404** (e.g., to mitigate the likelihood that a crack in an electrode **412**, **414** propagates through the carrier **404**); compatibility with a HAF or other adhesive; and good biocompatibility (e.g., not likely to cause an adverse reaction to a user of a device). In some embodiments, the electrodes **412**, **414** may include aluminum titanium nitride (AlTiN) or chromium silicon carbonitride (CrSiCN). AlTiN and CrSiCN hold up well to abrasion and corrosion and tend not to place undue stresses on a sapphire carrier.

FIG. **5**E shows an example deposition of adhesive on the interior surface **406** of the carrier **404**. The adhesive may be deposited in inner and outer rings **440**, **442**, as described with reference to FIG. **4**C. The inner ring **440** of adhesive may be positioned on the inner ring **500***a* of the first mask. The outer ring **442** of adhesive may be positioned on the second mask **508**, outward from the plurality of openings **420** in the second mask **508**. In some cases, the adhesive may include a PSA or HAF.

FIG. **6** shows a cross-section of the carrier **404** shown in FIG. **5**B, and illustrates an overlap between the first and second masks **500**, **508**. The second mask **508** may overlap the first mask (e.g., outer ring **500***b*) on the interior surface **406** of the carrier **404** such that the first mask **500** is positioned between the second mask **508** and the interior surface **406** of the carrier **404**.

FIG. **7** shows a cross-section of the carrier **404** shown in FIG. **5**C or **5**D, and illustrates an overlap between the first electrode **412** (or second electrode) and the first mask **500** (e.g., outer ring **500***b* of the first mask). The first electrode **412** may overlap the first mask **500** (or outer ring **500***b* of the first mask) on the interior surface **406** of the carrier **404**, such that the first mask **500** is positioned between the first electrode **412** and the interior surface **406** of the carrier **404**.

In some embodiments, the electrodes **412**, **414** shown in FIGS. **5**C, **5**D, and **7** may be formed using indium titanium oxide (ITO) or another transparent material. In these embodiments, the electrodes **412**, **414** may be transparent to light emitted by a sensor subsystem positioned below the carrier **404**, and thus the electrodes **412**, **414** may extend over a greater portion (or all) of the exterior surface **408** of the carrier **404**. FIG. **8** shows an example layer construction of an ITO-based electrode. As shown, the stack **800** may include a layer **802** of aluminum oxide (Al_2O_3) on the carrier, a layer **804** of ITO on the layer **802** of aluminum oxide, a first layer **806** of silicon dioxide (SiO_2) on the layer **804** of aluminum oxide, a layer **808** of silicon nitride (Si_3N_4) on the first layer **806** of silicon dioxide, a second layer **810** of silicon dioxide on the layer **808** of silicon nitride, and a layer **812** of diamond like carbon, or another hard coating, on the second layer **810** of silicon dioxide. Alternatively, the layer **808** of silicon nitride and second layer **810** of silicon dioxide may not be deposited, or only the layer **804** of ITO may be deposited, or just the layer **804** of ITO layer and first layer **806** of silicon dioxide may be deposited. Other variations in the number or types of layers may also be used to form the stack **800**. Each of the layers may be transparent to IR or visible light.

FIGS. **9**A-**9**C show alternative electrical connections between an electrode (e.g., an electrode on an exterior surface of a carrier that forms part of a housing of an electronic device) and an electrical contact interior to the electronic device. In some examples, the carriers shown in cross-section in FIGS. **9**A-**9**C may have circular perimeters. In other examples, the carriers may have perimeters that are oval-shaped, square-shaped, rectangular-shaped, and so on. The techniques described with reference to FIGS. **9**A-**9**C can be applied to carriers having various perimeter shapes, to carriers having different compositions, and so on. In some embodiments, the features shown in FIGS. **9**-**9**C may be replicated to electrically connect more than one electrode on an exterior surface of an electronic device to components interior to the electronic device.

In FIG. **9**A, the electrode **900** may be a thin film electrode that is PVD deposited on a surface **902** of a carrier **904**. The surface **902** on which the electrode **900** is deposited may be a surface of the carrier **904** that is exterior to an electronic device (i.e., the electrode **900** may be deposited on an exterior surface **902** of the carrier **904**). As shown, a conductive material used to form the electrode **900** may be deposited on the carrier **904** such that the material wraps around an edge **906** or perimeter of the carrier **904** to form an electrical contact **908** on a surface **910** of the carrier **904** that is interior to the electronic device (i.e., on an interior surface **910** of the carrier **904**). In some cases, the electrical contact **908** may be a tab that traces a much smaller arc about the periphery of the carrier **904** than the electrode **900** (as shown, for example, in FIGS. **5**C, **5**D, and **5**E). In other cases, the electrical contact **908** may be arc-shaped and trace an arc that is similar in size to an arc traced by the electrode **900** on the exterior surface **902** of the carrier **904**.

In some cases, the conductive material(s) used to form the electrode **900** and electrical contact **908** may be deposited on the exterior surface **902**, edge **906**, and interior surface **910** of the carrier **904** in a single operation (or single set of operations in which the material(s) are deposited on the exterior surface **902**, edge **906**, and interior surface **910** of the carrier **904**). In other cases, the material(s) used to form the electrode **900** may be deposited on the edge **906** or interior surface **910** of the carrier **904** in operations that are performed separately from one or more operations in which the electrode **900** is deposited on the exterior surface **902** of the carrier **904**. In these latter examples, the material(s) may be deposited such that the materials overlap. In some cases, a set of one or more materials used to form the electrode **900** may differ from a set of one or more materials deposited on the edge **906** or interior surface **910** of the carrier **904**.

In some embodiments, the conductive material(s) deposited on the exterior surface **902**, edge **906**, and interior surface **910** of the carrier **904** may include a layer of SUS or a layer of DLC. In other embodiments, only the electrode **900** or edge **906** of the carrier **904** may be coated with a layer of stainless steel or DLC. In some examples, the conductive material(s) may include a PVD deposited layer of AlTiN or CrSiCN.

In some embodiments, one or more masks (e.g., one or more ink masks) may be applied to the interior surface of the carrier (e.g., as described with reference to FIGS. **5**A-**5**E, **6**, & **7**). In these embodiments, one or more of the conductive materials used to form the electrode **900** and electrical contact **908** may be applied over the mask(s). The conductive material(s), and the manner in which the conductive material(s) are deposited on the carrier **904**, may therefore be selected to ensure adhesion of the conductive material(s) to the carrier **904** and to the ink or other material used to form the mask(s).

As shown in FIG. **9**A, a peripheral band of the interior surface **910** of the carrier **904** may be attached to a recessed ledge **912** in another housing member **914** of the electronic device (e.g., with the carrier **904** overlapping the housing member **914**). In such an embodiment, the carrier **904** may be attached to the housing member **914** using an adhesive **916**, such as a heat-activated film (HAF). The adhesive **916** or conductive material(s), and the manner in which the carrier **904** is attached to the housing member **914**, may therefore be selected to ensure adhesion of the carrier **904** to the housing member **914**.

The electrical contact **908** may have a great enough width (e.g., a great enough width along a radius of the carrier **904**) that the electrical contact **908** extends past the recessed

ledge **912** in the housing member **914** when the carrier **904** is attached to the housing member **914**, making the electrical contact **908** accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrical contact **908**, to enable a signal to be received from or applied to the electrode **900**.

In FIG. **9**B, the electrode **918** may be a thin film electrode that is PVD deposited on a surface **920** of a carrier **922**. The surface **920** on which the electrode **918** is deposited may be a surface of the carrier **922** that is exterior to an electronic device (i.e., the electrode **918** may be deposited on an exterior surface **920** of the carrier **922**). Prior to or after depositing the electrode **918** on the carrier **922**, a thru-carrier via **924** may be drilled or otherwise cut into the carrier **922**. The thru-carrier via **924** may extend from the exterior surface **920** of the carrier **922** (or electrode **918**) to the interior surface **926** of the carrier **922**. The via **924** may be coated or filled with a conductive material **928** such as stainless steel (SUS), and the conductive material **928** may be covered by, overlap, or otherwise electrically connect to the electrode **918**. In some cases, the conductive material **928** in the via **924** may be molded or glued in the via **924**. The conductive material **928** may provide an electrical contact **930** on a surface **926** of the carrier **922** that is interior to an electronic device (i.e., on an interior surface of the carrier). In some cases, the conductive material **928** in the via **924** may overlap a portion of the interior surface **926** of the carrier **922**, or may be connected to another conductive element deposited on the interior surface **926** of the carrier **922**.

The conductive material(s) used to form the electrode **918** and deposited in the via **924** may be the same or different. In some embodiments, the conductive material(s) used to form the electrode **918** may include a layer of stainless steel (SUS) or a layer of diamond like carbon (DLC). In some examples, the conductive material(s) may include a PVD deposited layer of Aluminum Titanium Nitride (AlTiN) or Chromium Silicon Carbon Nitride (CrSiCN).

As shown in FIG. **9**B, a peripheral band of the interior surface **926** of the carrier **922** may be attached to a recessed ledge **932** in another housing member **934** of the electronic device (e.g., with the carrier **922** overlapping the housing member **934**). In such an embodiment, the carrier **922** may be attached to the housing member **934** using an adhesive **936**, such as a HAF. The adhesive **936**, and the manner in which the carrier **922** is attached to the housing member **934**, may therefore be selected to ensure adhesion of the carrier **922** to the housing member **934**.

When the carrier **922** is attached to the housing member **934**, the via **924** may be positioned such that it overlaps the recessed ledge **932** or is interior to the recessed ledge **932**, making the electrical contact **930** accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrical contact **930**, to enable a signal to be received from or applied to the electrode **918**.

In FIG. **9**C, the electrode **938** may be a metallic arc-shaped element positioned between a carrier **940** and another housing member **942** of an electronic device. In some embodiments, the electrode **938** may be a singular metallic ring-shaped electrode (e.g., one electrode). In these embodiments, a peripheral band of a surface of the carrier **940** that is interior to the electronic device (e.g., an interior surface **944** of the carrier **940**) may be attached to a recessed ledge **946** in the electrode **938** (e.g., with the carrier **940**

overlapping the electrode **938**), and the electrode **938** may be attached to a recessed ledge **950** in the housing member **942** (e.g., with the electrode **938** overlapping the housing member **942**). In other embodiments, the electrode **938** may be arc-shaped and may be one of two or more arc-shaped electrodes between the carrier **940** and the housing member **942**. In these embodiments, a peripheral band of the interior surface of the carrier **940** may be attached to recessed ledges **946** in multiple arc-shaped electrodes **938** (e.g., with the carrier **940** overlapping the electrodes **938**), and each of the arc-shaped electrodes **938** may be attached to the recessed ledge **950** in the housing member **942** (e.g., with the electrodes **938** overlapping the housing member **942**). In some cases, the multiple arc-shaped electrodes **938** may be electrically isolated from each other by flexible seals or gaskets, or by rigid separators (e.g., rigid extensions of the housing member **942**, which rigid extensions may include extensions of the recessed ledge **950** to which the electrodes **938** are attached. In some cases, the electrode **938** may be attached to the housing member **942** before the carrier **940** is attached to the electrode **938**.

The electrode **938** may be formed of a conductive material including a layer of stainless steel (SUS) or DLC. In some examples, the conductive material may include a PVD deposited layer of Aluminum Titanium Nitride (AlTiN) or Chromium Silicon Carbon Nitride (CrSiCN). A surface **954** of the electrode **938** interior to the electronic device may provide an electrical contact for connecting components interior to the electronic device to the electrode **938**.

In some cases, an edge **956** or perimeter of the carrier **940** may be abutted directly to the electrode **938**, and an edge **958** of the electrode **938** may be abutted directly to the housing member **942**. In other cases, an adhesive, seal, gasket, or filler may fill a gap between the carrier **940** and the electrode **938** or a gap between the electrode **938** and the housing member **942**.

As shown in FIG. **9**C, a peripheral band of the interior surface **944** of the carrier **940** may be attached to a recessed ledge **946** in the electrode **938**, and a peripheral band of an interior surface **954** of the electrode **938** may be attached to the housing member **942**. In such an embodiment, the carrier **940** may be attached to the electrode **938** or the electrode **938** may be attached to the housing member **942** using an adhesive **948** or **952**, such as a HAF. The adhesive **948** or **952**, and manner in which the respective elements are attached, may therefore be selected to ensure adhesion of the carrier **940** to the electrode **938** (or adhesion of the electrode **938** to the housing member **942**).

When the electrode **938** is attached to the housing member **942**, the electrode **938** may be positioned such that it overlaps the recessed ledge **950** or is interior to the recessed ledge **950**, making the electrode **938** accessible interior to the electronic device. In some cases, a flex circuit, other flexible conductor, or other conductive element may be soldered or otherwise electrically connected to the electrode **938**, to enable a signal to be received from or applied to the electrode **938**.

FIGS. **10**A-**10**D show alternative carrier profiles, and alternative attachments (e.g., structural attachments) of carriers to other housing members of an electronic device. In some examples, the carriers may have circular perimeters. In other examples, the carriers may have perimeters that are oval-shaped, square-shaped, rectangular-shaped, and so on. The techniques described with reference to FIGS. **10**A-**10**D can be applied to carriers having various perimeter shapes, to carriers having different compositions, and so on. Each of FIGS. **10**A-**10**D shows an exterior surface (e.g., a back surface) of an electronic device, such as an electronic watch, and a cross-section of the exterior surface of the electronic device.

In FIG. **10**A, a carrier **1000** is attached to another housing member **1002** of an electronic device. The carrier **1000** includes an exterior surface **1004** that forms a part of the exterior surface of the electronic device, and an interior surface **1006** that faces components interior to the electronic device.

A peripheral band of the interior surface **1006** of the carrier **1000** may be attached to a recessed ledge **1064** in the housing member **1002** (e.g., with the carrier **1000** overlapping the housing member **1002**). In such an embodiment, the carrier **1000** may be attached to the housing member **1002** using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier **1000** is attached to the housing member **1002**, may be selected to ensure adhesion of the carrier **1000** to the housing member **1002**.

The carrier **1000** may be variously configured, but in FIG. **10**A, an inner portion **1008** of the interior surface **1006** of the carrier **1000**, such as a portion of the carrier interior to a number of thru-carrier vias **1010**, is flat. An outer portion **1012** of the interior surface **1006**, such as a portion outside the number of thru-carrier vias **1010**, is concave or inwardly-sloped (downwardly-sloped in the figure) with respect to the inner portion **1008** of the interior surface **1006**. In contrast, the exterior surface **1004** of the carrier **1000** may be convex. Thus, the thickness of the carrier **1000** may vary to some degree from its center axis to its perimeter.

In some embodiments, one or more arc-shaped electrodes **1014** (e.g., two electrodes) may be positioned around the exterior surface **1004** of the carrier **1000**, inward from the perimeter of the carrier **1000**. In other embodiments, the electrodes **1014** may have other shapes or may extend to or around the perimeter. The electrodes **1014** may be PVD deposited thin film electrodes. In some cases, the electrodes **1014** may be connected to interior components of the electronic device by the thru-carrier vias **1010**, which in some cases may be drilled or formed through the flat inner portion **1008** of the interior surface **1006** of the carrier **1000**. In other cases, the electrodes **1014** may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier **1000**, or in any of the ways shown in FIGS. **9**A-**9**C.

In some cases, components such as a sensor subsystem may be attached to the inner, flat portion of the interior surface **1006** of the carrier **1000**.

In FIG. **10**B, a carrier **1016** is attached to another housing member **1018** of an electronic device. The carrier **1016** includes an exterior surface **1020** that forms a part of the exterior surface of the electronic device, and an interior surface **1022** that faces components interior to the electronic device.

A peripheral band of the interior surface **1022** of the carrier **1016** may be attached to a recessed ledge **1024** in the housing member **1018** (e.g., with the carrier **1016** overlapping the housing member **1018**). In such an embodiment, the carrier **1016** may be attached to the housing member **1018** using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier **1016** is attached to the housing member **1018**, may be selected to ensure adhesion of the carrier **1016** to the housing member **1018**.

The carrier **1016** may be variously configured, but in FIG. **10**B, the carrier **1016** has a uniform thickness. The interior surface **1022** of the carrier **1016** may be concave, and the exterior surface **1020** of the carrier **1016** may be convex. To provide a flat surface for connecting components (e.g., a

sensor subsystem) to the carrier **1016**, a secondary carrier **1026** having a convex exterior surface **1028** and a flat interior surface **1066** may be attached to an inner portion of the interior surface **1022** of the carrier **1016**. The secondary (or interior) carrier **1026** may be attached to the primary (or exterior) carrier **1016** using a transparent adhesive. In some cases, the secondary carrier **1026** may be attached to the primary carrier **1016** interior to a number of thru-carrier vias **1030**.

In some embodiments, one or more arc-shaped electrodes **1032** (e.g., two electrodes) may be positioned around the exterior surface of the carrier **1016**, inward from the perimeter of the carrier **1016**. In other embodiments, the electrodes **1032** may have other shapes or may extend to or around the perimeter. The electrodes **1032** may be PVD deposited thin film electrodes. In some cases, the electrodes **1032** may be connected to interior components of the electronic device by the thru-carrier vias **1030**. In other cases, the electrodes **1032** may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier **1016**, or in any of the ways shown in FIGS. **9**A-**9**C.

FIGS. **10**C & **10**D each show a carrier attached to another housing member of an electronic device. The carrier includes an exterior surface that forms a part of the exterior surface of the electronic device, and an interior surface that faces components interior to the electronic device. In each of FIGS. **10**C & **10**D, the carrier has a flat interior surface and a convex exterior surface. The carriers shown in FIGS. **10**C & **10**D may be easier to manufacture than the carriers shown in FIGS. **10**A & **10**B.

In FIG. **10**C, a carrier **1034** is attached to another housing member **1036** of an electronic device. The carrier **1034** includes an exterior surface **1038** that forms a part of the exterior surface of the electronic device, and an interior surface **1040** that faces components interior to the electronic device.

A peripheral band of the interior surface **1040** of the carrier **1034** may be attached to a recessed ledge **1042** in the housing member (e.g., with the carrier **1034** overlapping the housing member **1036**). In such an embodiment, the carrier **1034** may be attached to the housing member **1036** using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier **1034** is attached to the housing member **1036**, may be selected to ensure adhesion of the carrier **1034** to the housing member **1036**.

In some embodiments, one or more arc-shaped electrodes **1044** (e.g., two electrodes) may be positioned around the perimeter of the exterior surface **1038** of the carrier **1034**. In other embodiments, the electrodes **1044** may have other shapes or other positions on the exterior surface **1038** of the carrier **1034**. The electrodes **1044** may be PVD deposited thin film electrodes. In some cases, the electrodes **1044** may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier **1034**, or in any of the ways shown in FIGS. **9**A-**9**C.

In some cases, components such as a sensor subsystem may be attached to the interior surface **1040** of the carrier **1034**.

In FIG. **10**D, a carrier **1060** is attached to another housing member **1046** of an electronic device (e.g., an electronic watch), similarly to how the carrier **1034** is attached to another housing member **1036** in FIG. **10**C. For example, a peripheral band of the interior surface **1048** of the carrier **1060** may be attached to a recessed ledge **1050** in the housing member **1046** (e.g., with the carrier **1060** overlapping the housing member **1046**). The carrier **1060** may be attached to the housing member **1046** using an adhesive, such as a HAF. The adhesive, and the manner in which the carrier **1060** is attached to the housing member **1046**, may be selected to ensure adhesion of the carrier **1060** to the housing member **1046**.

The housing member **1046** to which the carrier **1060** is attached may be attached to yet another housing member (e.g., a second housing member **1052**). A peripheral band of the interior surface **1054** of the first housing member **1046** may be attached to a recessed ledge **1056** in the second housing member **1052** (e.g., with the first housing member **1046** overlapping the second housing member **1052**). The first housing member **1046** may be attached to the second housing member **1052** using an adhesive, such as a HAF. The adhesive, and the manner in which the first housing member **1046** is attached to the second housing member **1052**, may be selected to ensure adhesion of the first housing member **1046** to the second housing member **1052**. In some cases, the first housing member **1046** may electrically insulate the electrodes **1058** on the carrier **1060** from the second housing member **1052**, or may provide a transition between incompatible materials, or may provide a support for the carrier **1060**, or may facilitate assembly of the housing of the electronic device.

In some embodiments, one or more arc-shaped electrodes **1058** (e.g., two electrodes) may be positioned around the perimeter of the exterior surface of the carrier **1060**. In other embodiments, the electrodes **1058** may have other shapes or other positions on the exterior surface **1062** of the carrier **1060**. The electrodes **1058** may be PVD deposited thin film electrodes. In some cases, the electrodes **1058** may be connected to interior components of the electronic device by conductive material that wraps around the edge or perimeter of the carrier, or in any of the ways shown in FIGS. **9**A-**9**C.

In some cases, components such as a sensor subsystem may be attached to the interior surface **1048** of the carrier **1060**.

Turning now to the implementation of an electrode on a crown, FIG. **11**A shows an example elevation of a crown assembly **1100**. The crown assembly **1100** may be an example of a crown assembly included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. The crown assembly **1100** may include a crown **210**.

The crown **210** may be mechanically and electrically connected to a shaft **1102** that extends through an opening in a housing. By way of example, the housing is shown to be the housing **206** of the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B. The crown **210** may be integrally formed from a single piece of material that includes the shaft **1102** (that is, they may be connected to one another), or the shaft **1102** may be semi-permanently attached to a crown body **1104** using a fastening means such as solder, threads, or an adhesive. The crown **210** (or at least the crown body **1104**) may be external to the housing **206**, and may be rotated and/or translated by a user of the electronic device incorporating the crown assembly **1100**. Further, although the crown body **1104** and shaft **1102** are shown as integrally formed in FIGS. **11**A and **11**B, it should be appreciated that they may be separate pieces that are joined together.

The crown assembly **1100** may further include a shaft retainer **1106** receiving an end of the shaft **1102**. The shaft retainer **1106** may be mechanically and/or electrically connected to the shaft **1102** (e.g., using solder, threads, or an

adhesive), interior to the housing **206**. The shaft retainer **1106** may retain the crown **210** in position in relation to the housing **206**.

One or more insulators **1108** (e.g., electrical insulators) may electrically insulate the crown **210** and/or shaft **1102** from the housing **206**. The term "insulator" encompasses both a single insulator and multiple insulators taken as a set. The insulator **1108** is generally shown in FIG. **11** as an annular seal having an L-shaped profile, functioning as a collar for the shaft. The shaft **1102** and crown body **1104** may translate, moving toward and away from the housing **206** while the insulator **1108** and shaft retainer **1106** move with the shaft **1102**. In some embodiments, the insulator **1108** may be stationary relative to the housing **206** while the shaft **1102**, crown body **1104** and shaft retainer **1106** move.

The insulator **1108** or seal electrically insulates the shaft **1102** from the housing **206**, and may also electrically insulate the housing **206** from the shaft retainer **1106**. In some embodiments, the insulator **1108** may alternatively include more than one element and/or be positioned elsewhere within the crown assembly **1100**. For example, the insulator **1108** may include an element, layer, or coating **1108***a* applied to a surface of the housing **206** that faces an underside of the crown **210**, or to other elements that face the underside of the crown **210**.

A tactile switch **1110** may be axially aligned with the shaft **1102** and positioned at an end of the shaft **1102** opposite the crown body **1104**. By way of example, the tactile switch **1110** may be attached on a substrate **1112**. The tactile switch **1110** may be actuated (e.g., switched between two or more states) as the shaft **1102** translates along an axis of the shaft **1102** to provide a crown input. A spring-biased conductor **1114** may be mechanically and electrically connected to at least one of the shaft **1102** or the shaft retainer **1106**, and in FIG. **11** is shown to be connected to the shaft retainer **1106**. The spring-biased conductor **1114** may be biased to electrically contact the shaft **1102** and/or shaft retainer **1106** during all phases of rotation and translation of the crown **210**, and may electrically connect the shaft **1102** and/or shaft retainer **1106** to a circuit **1116** (e.g., a processor). When the crown is translated by a user, the spring-biased conductor **1114** may deform to maintain electrical contact with the shaft **1102** and/or shaft retainer **1106**.

The crown assembly **1100** may further include an optical encoder **1118**. The optical encoder **1118** may be used to detect rotation and/or translation of the shaft **1102** or shaft retainer **1106**. In some embodiments, the circuit **1116** and optical encoder **1118** may be attached to the same substrate as the tactile switch **1110**.

In some embodiments, the entirety of the crown **210** or crown body **1104** may be conductive and function as an electrode. The conductive crown body **1104** may be electrically connected to the circuit **1116** via the shaft **1102**, shaft retainer **1106**, and spring-biased conductor **1114**. In other embodiments, only a portion of the crown **210** or crown body **1104** may be conductive and function as an electrode, and the conductive portion of the crown body **1104** may be electrically connected to the circuit **1116** via the shaft **1102**, shaft retainer **1106**, and spring-biased conductor **1114**.

Because the signals received by or propagated from the crown **210** may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the crown **210** can have a significant impact on the ability of the circuit **1116** to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the crown assembly **1100**. The materials, positions, electrical connections to, and electrical routing paths for the crown assembly **1100** can also determine how well the crown assembly **1100** receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the crown **210** and internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the crown assembly **1100** operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator **1108** may be positioned to prevent moisture from electrically shorting the crown **210** to the housing **206**, or the housing **206** may be grounded to provide electrical shielding for some or all of the signals propagated through the crown assembly **1100**, or the interfaces between the shaft **1102** and the shaft retainer **1106**, or between the shaft retainer **1106** and the spring-biased conductor **1114**, may be configured to increase SNR and reduce signal attenuation.

In some embodiments, the crown **210** may include a coating, layer, or the like **1120** ("coating **1120**") that electrically isolates the crown **210**. The coating may thus function as, have similar properties to, and/or be made from the same or similar materials as, the insulator **1108**. Generally, the coating **1120** prevents electrical connection between the crown **210** and the housing **206**, for example when water is present in the space between the crown and housing.

In the absence of the coating **1120**, water, sweat, or another conductor may electrically bridge or short the crown **210** to the housing **206**, presuming both the crown and housing are made from (or incorporate) an electrical conductor such as metal. In the event the crown **210** or some portion thereof serves as an electrode for measuring an electrocardiogram, shorting the crown **210** to the housing **206** (and thus to the skin of a wearer) may render the crown inoperable or the electrocardiogram unreliable.

The coating **1120** serves as a barrier against shorting the crown **210** to the housing **206** or other electrically conductive material or body, thereby ensuring the electrical functionality of the crown **210**. In some embodiments the coating **1120** coats only those surfaces of the crown that oppose or face the housing; in other embodiments and as shown in FIG. **11**A, the coating **1108***a* may extend across one or more sides of the crown **210**. Further, the coating **1120** may extend onto a top or outer surface of the crown **210** (e.g., the surface of the crown that does not oppose or face the housing **206**), although typically at least a portion of the outer surface is not covered by the coating in order to define an area of the crown that can electrically couple to a wearer's finger.

The coating **1120** also may extend at least partly down a shaft of the crown **210**, as discussed in more detail with respect to FIG. **11**B.

In some embodiments, a second coating **1122** may be applied to the housing **206** instead of, or in addition to, the coating **1120** on the crown **210**. This housing coating **1122** serves the same function as the crown coating **1120**, namely electrically insulating the housing **206** from the crown **210** when water or other electrical conductors are in the gap between the housing and crown. The housing coating **1122** may extend across the insulator **1108** (or a non-insulating collar), in some embodiments. Likewise, the housing coating **1122** may extend between the housing **206** and insulator **1108** in some embodiments, or may be an extension of the insulator.

In some embodiments, the coatings **1120**, **1122** may improve wear or provide a cosmetic function (e.g., provide an accent or visually conceal a surface of the shaft, crown,

and/or housing) for the crown assembly **1100**. Alternatively, the housing **206**, or that portion of the housing **206** that faces the crown **210**, may be formed from a material that operates as an electrical insulator (e.g., plastic, ceramic, or the like). In some embodiments, one or more of the insulators **1108** (including element, layer, or coating **1108***a* or **1120**) may by overmolded liquid crystal polymer (LCP) elements or coatings, which can provide very good separation resistance (high separation resistance) between moving or other parts. LCP layers may also be used in place of polyimide layers in flex circuits and other elements, and may not require the use of temperature or moisture-sensitive adhesives. LCP elements, layers, and coatings absorb less moisture than polyimides in high temperature and high humidity environments, which can be useful in maintaining high separation resistance between components when sensing low voltage signals (e.g., biometric signals of a person) under varying conditions (e.g., under non-controlled conditions outside a doctor's office or hospital). LCP elements, layers, and coatings also maintain good separation resistance high temperatures. Other elements, layers, or coatings that may be used to provide electrical isolation include silicone or acrylic elements, layers, or coatings, or other elements having a high surface resistance. Other examples of insulators or insulator positions are described with reference to FIGS. **11**B, **12**A, **12**B, **13**, & **14**.

FIG. **11**B shows another example crown **210** extending through a housing **206** of an electronic watch. As with other embodiments described herein, the crown **210** may be used to provide multiple types of input. For example, the crown may rotate about an axis of rotation (typically extending along a center length of the shaft **1102**, from an exterior of the housing **206** to an interior of the housing) to provide a first type of crown input, translate along the axis of rotation (e.g., move towards and/or away from the housing **206**) to provide a second type of crown input, and be touch-sensitive to provide a third type of crown input. The first and second types of input may control graphical output on the electronic watch's display, as described below in more detail with respect to FIGS. **26**A-**28**B. The third type of input may be a measurement of an electrical signal (such as voltage, capacitance, current, or the like), or facilitating measurements of a differential in an electrical signal, to provide an ECG of a user. That is and as discussed in greater detail herein, the third type of input may be the crown **210** functioning as one of two electrodes in an electrical circuit configured to measure a user's ECG. Typically, although not necessarily, the second electrode is positioned a back of the electronic watch. This second electrode and its functionality is discussed in more detail elsewhere in this document.

The crown **210** may be formed from multiple elements attached together, as discussed in more detail below, or may be a single piece and connected to one another. The crown **210** generally includes a crown body **1104** coupled to (or formed with) a shaft **1102**. The shaft **1102** of the crown may extend through the housing **206** and is typically received in, or passes through, a collar **1124**. The collar **1124** may restrict tilting of the shaft **1102** and crown body **1104**. Further, the collar **1124** may permit translation of the shaft **1102** and crown body **1104** toward and away from the housing and rotation of the shaft and crown body **1104** about the axis of rotation. The collar **1124** may be the same as, or similar to, the shaft retainer **1106** and/or insulator **1108** of FIG. **11**A.

One or more O-rings **1134** are fitted about the shaft **1102** and within the collar **1124**. The O-rings **1134** may be received within grooves, depressions, or the like within one or both of the shaft **1102** and collar **1124**. The O-rings form

a watertight seal and likewise reduce or eliminate contaminants passing into an interior of the housing **206** through the gap **1136** between the crown **210** and housing **206**. The O-rings **1134** may also permit the shat to rotate and/or translate while restricting (or helping to restrict) how far the shaft **1102** translates.

As with the embodiment shown in FIG. **11**A, the crown **210** may short to the housing **206** if water or another conductor is present in the gap **1136** between the crown and housing and the two are not electrically insulated from one another. Shorting the crown **210** to the housing **206** results in the electronic watch unreliably measuring and displaying an ECG of a user or not functioning at all.

Accordingly and similar to the embodiment of FIG. **11**A, an underside of the crown **210** may be coated with an electrically insulating coating **1132**. The coating **1132** may prevent water or another contaminant from acting as a short or ground path between the crown **210** and housing **206**. As discussed with respect to FIG. **11**A and shown in that figure, such a coating may be applied to the housing **206** in addition to, or instead of, the crown **210**.

The crown **210** shown in FIG. **11**B is not formed from a single piece of material but instead is formed from multiple elements. The crown body **1104** and shaft **1102** may be formed from or as a single piece of material, for example metal or another suitable conductor, and provide an electrical path between an object touching the crown body **1104** and a sensor within the housing **206**, such as the third sensor **230** discussed above. An insulating split **1146** may separate the crown body from a trim **1148**; the trim **1148** may be annular, square, or any other suitable shape. The trim and split **1146** may provide various aesthetic looks as well as functional properties, such as different wear resistance, environmental resistance, and the like as compared to the crown body **1104**. Accordingly, the trim **1148** may be made from the same material or a different material as the crown body **1104** and the shaft **1102**.

Insofar as the split **1146** is an electrical insulator, the coating **1132** need not extend across the split or onto any portion of the trim **1148** (although it can in some embodiments). Thus, the coating **1132** may stop at an edge of the crown body **1104** abutting the split **1146**. This may reduce manufacturing and assembly complexity of embodiments, as well as provide cost savings.

In addition to, or instead of, providing a coating **1132** on the crown **210** or housing **206**, the collar **1124** may be coated. For example, an electrically insulating coating **1126** may be deposited on the collar **1124** and serve to electrically insulate the collar from the housing **206** and/or crown **210**. This may be useful when the collar is made from an electrically conductive material and the crown **210** may be shorted to the collar **1124**, in addition to or instead of to the housing **206**.

As one non-limiting example, capillary action may retain water (or another liquid) in a portion of the gap between the collar **1124** and crown **210** while the part of the gap **1136** between the crown and housing **206** is sized to permit water to drain out. Thus, in such an embodiment the crown **210** may be at risk of electrically shorting to the collar **1124** but not the housing **206**. It should be appreciated that in some embodiments the housing **206** and/or crown **210** may be coated as well as the collar **1124**. It should likewise be appreciated that any or all of the electrically insulating coatings described herein may attenuate noise with respect to a signal conducted from the crown body **1104** through the

shaft **1102** to a sensor, thereby providing more accurate and/or faster readings of a biological parameter such as an ECG.

Although the coating **1126** (and coating **1132**) has been discussed as an electrical insulator, it should be appreciated that the coating(s) may provide other properties in addition to, or instead of, electrical insulation. For example, the coating **1126** may reduce friction between the collar **1124** and shaft **1102** as the shaft **1102** rotates and/or translates. The coating **1126** may reduce wear on either or both of the collar **1124** and shaft **1102** as another example.

Further, in some embodiments the gap **1136** between the crown **210** and housing **206** may be large enough that the collar **1124** may be visible. In order to obscure the first collar coating and/or the collar, a second collar coating **1128** may be applied over the first, insulating collar coating **1126**. The second collar coating **1128** may be darker or otherwise visually conceal the first collar coating **1128** and collar **1124** from the naked eye.

As yet another option, the second coating **1128** may also provide environmental resistance and/or resist wear, tear, and/or friction between the collar **1124** and shaft **1102**, as described above. Thus, the first collar coating **1126** may be an electrical insulator while the second collar coating **1128** may be chosen for its other material properties and/or resistances. Similarly, the first collar coating may be chosen for its material properties and/or resistances (including functioning as an electrical insulator) and the second collar coating may be used to obscure the first collar coating.

Any or all of the coatings described herein may be deposited in a number of ways, including electrophoretic deposition or other manners that are suitable and known in the art. Likewise, any or all of the coatings may incorporate materials such as titanium dioxide, Teflon, or the like to provide or enhance properties such as resistance to wear, lowering of friction between adjacent elements, and the like. In some embodiments the first collar coating **1126** (or any other coating) may be approximately 10-30 microns thick or even 5-50 microns. The second collar coating **1128** (or any other coating) may be thinner on the order of 3-5 microns or even 2-10 microns.

More detailed examples of the crown assembly **1100** described with reference to FIG. **11**A are shown in FIGS. **12**A, **12**B, **13**, & **14**.

Turning now to FIGS. **12**A & **12**B, there is shown an example of a crown assembly **1200**, as may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. FIG. **12**A shows an exploded view of the crown assembly **1200**, and FIG. **12**B shows an assembled cross-section of the crown assembly **1200**, as viewed from the front or rear face of an electronic device such as the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B.

The crown assembly **1200** is an example of the crown assembly **1100** shown in FIG. **11**, and includes components corresponding to the crown **210**, shaft retainer **1106**, insulator **1108**, tactile switch **1110**, substrate **1112**, spring-biased conductor **1114**, circuit **1116**, and optical encoder **1118**.

The crown assembly **1200** may include a conductive rotatable shaft **1202** configured to extend through an opening in a housing **1242** (see FIG. **12**B), such as the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, **4**B, or **11**. A user-rotatable crown **1204** may be mechanically attached to the shaft **1202** exterior to the housing **1242**. The crown **1204** may be rotated by a user of an electronic watch, to in turn rotate the shaft **1202**. In some cases, the crown **1204** may also be pulled or pushed by the user to translate the shaft **1202** along its axis. The crown **1204** may be electrically connected to a circuit within the housing **1242**, but electrically isolated from the housing **1242**.

The crown **1204** may be electrically connected to the shaft **1202**. In some cases, at least part of the crown **1204** and at least part of the shaft **1202** may be molded, machined, or otherwise formed together (e.g., from a same material, such as a conductive ceramic or stainless steel).

In some embodiments, the crown **1204** may be formed of a conductive ceramic or stainless steel (or have a conductive ceramic or stainless steel core). The core may be coated in a PVD deposited layer of SUS or DLC, or an electrodeposited (ED) layer of AlTiN or CrSiCN, and may function as an electrode. In some embodiments, the crown **1204** may have a conductive crown body **1244** surrounded by a ring **1246** of non-conductive material (or other insulator). See, FIG. **12**B. The non-conductive ring **1246** may help prevent shorting of the crown **1204** to the housing **1242**. The ring **1246** of non-conductive material may in some cases be surrounded by another ring **1248** of conductive material. In the configuration shown, the ring **1248** may optionally contact and electrically short to a grounded housing **1242** when the crown is pressed, thereby helping to electrically shield the conductive crown body **1244** of the crown **1204** from some sources of interference. In some embodiments, the crown **1204** may have a conductive surface covered by a thin non-conductive coating. The non-conductive coating may provide a dielectric for capacitive coupling between the conductive surface and skin of a user of the crown **1204** (or an electronic watch or other device that includes the crown assembly **1200**). In the same or different embodiments, the crown **1204** may have a non-conductive coating on a surface of the crown **1204** facing the housing **1242**.

A shaft retainer **1206** may be mechanically connected to the shaft **1202**, interior to the housing **1242** (e.g., interior to a watch body housing), after the shaft is inserted through the opening in the housing **1242** with the crown **1204** positioned exterior to the housing **1242**. In some cases, the shaft retainer **1206** may include a nut, and the shaft **1202** may have a threaded male portion that engages a threaded female portion of the nut. In some cases, the shaft retainer **1206** may be conductive, or have a conductive coating thereon, and mechanical connection of the shaft retainer **1206** to the shaft **1202** may form an electrical connection between the shaft retainer **1206** and the shaft **1202**. In an alternative embodiment (not shown), the shaft retainer **1206** may be integrally formed with the shaft **1202**, and the shaft **1202** may be inserted through the opening in the housing **1242** from inside the housing **1242** and then attached to the crown **1204** (e.g., the crown **1204** may screw onto the shaft **1202**).

In some embodiments, a collar **1208** may be aligned with the opening in the housing **1242**, and a collar retainer **1210** may be coupled to the collar **1208** to retain the collar **1208** to the housing **1242** from a side of the housing **1242** opposite a side of the housing **1242** in which the collar **1208** is inserted. In some embodiments, the collar retainer **1210** may be coupled to the collar **1208** via threads on a male portion of the collar **1208** and corresponding threads on a female portion of the collar retainer **1210**. Optionally, a gasket **1212** (e.g., an I-ring) made of a synthetic rubber and fluoropolymer elastomer (e.g., Viton), silicone, or another compressible material may be placed over the collar **1208** prior to insertion of the collar **1208** through the opening, and attachment of the collar retainer **1210** to the collar **1208** may compress the gasket **1212**. The compressed gasket **1212** may provide stability to the collar **1208** and collar retainer **1210**, or provide a moisture barrier between the collar **1208** and the

housing **1242**. The collar **1208** and collar retainer **1210** may be attached to one another, and thereby to the housing **1242**, prior to insertion of the shaft **1202** through the collar **1208**. Another gasket **1214** (e.g., a Y-ring) made of Viton, silicone, or another compressible material may be placed over the collar **1208**, before or after insertion of the collar **1208** through the opening, but before the shaft **1202** is inserted through the collar **1208**. The second gasket **1214** may provide a moisture barrier between the crown **1204** and the housing **1242** or the crown **1204** and the collar **1208**.

Also prior to inserting the shaft **1202** through the collar **1208**, and in some cases prior to inserting the collar **1208** into the opening in the housing **1242**, an insulator **1216** may be inserted into or deposited on the interior of the collar **1208**, or placed around or deposited on the shaft **1202**. The insulator **1216** may also be inserted, placed, or deposited as the shaft **1202** is inserted into the collar **1208**. In some cases, the insulator **1216** may include a non-conductive sleeve or bushing (e.g., a plastic sleeve) inserted (e.g., press-fit) into the collar **1208** (e.g., into a portion of the collar **1208** positioned interior to the housing **1242**). The insulator **1216** may also or alternatively include a non-conductive sleeve overmolded on the collar (e.g., molded within the opening in the collar **1208** and over a surface of the collar **1208** facing the crown **1204**). In some cases, the insulator **1216** may be an overmolded liquid crystal polymer (LCP) insulator **1216**. The insulator **1216** may also or alternatively include a non-conductive coating on the collar **1208** (e.g., on an inner surface of the collar **1208**), or a non-conductive coating on the shaft **1202**, or a set of one or more non-conductive gaskets surrounding the shaft **1202**. When the shaft **1202** is inserted into the collar **1208**, the insulator **1216** may be positioned between the shaft **1202** and the collar **1208** and help to insulate a conductive portion of the shaft **1202** (or the entire shaft **1202**) from the collar **1208**.

Another insulator **1218** may be positioned between the shaft retainer **1206** and the collar retainer **1210**. For example, a non-conductive (e.g., plastic) washer, plate, or shim may be attached to the interior of the collar retainer **1210**, between the shaft retainer **1206** and the collar retainer **1210**. In some cases, the non-conductive washer may be carried by a plate **1220**, such as a plate formed of stainless steel (e.g., the insulator **1218** may be an overmolded LCP insulator **1218**). In these cases, the non-conductive washer may be attached to the interior of the collar retainer **1210** by welding (e.g., laser welding) the plate **1220** to the collar retainer **1210**. The non-conductive washer or other element may provide a bearing surface for the shaft retainer **1206**.

As shown in FIGS. 12A & 12B, one or more O-rings **1222**, **1224** or other gaskets may be placed over the shaft **1202** before the shaft **1202** is inserted into the collar **1208**. The O-rings **1222**, **1224** may be formed of a synthetic rubber, fluoropolymer elastomer, silicone, or another compressible material. The O-rings **1222**, **1224** may maintain the shaft **1202** in a position that is centered within the collar **1208**. In some cases, the O-rings **1222**, **1224** may provide a seal between the shaft **1202** and the collar **1208**. The O-rings **1222**, **1224** may also function as an insulator between the shaft **1202** and the collar **1208**. In some embodiments, the O-rings **1222**, **1224** may be fitted to recesses in the shaft **1202**. Additionally, a low-friction ring **1306** or filler may be placed around the top of the collar **1208**, between the crown **1204** and the collar **1208**. Alternatively, the low-friction ring **1250** or filler may be attached to the crown **1204**, between the crown **1204** and the collar **1208**. In some embodiments, the shaft **1202** may be smooth (not shown) and rotate within a thicker or closer fitting insulator **1216** without use of the O-rings **1222**, **1224**.

In some embodiments, a bracket **1226** may be attached (e.g., laser welded) to the collar retainer **1210** or another element within the housing **1242**. The bracket **1226** may support a spring-biased conductor **1228** and maintain the spring-biased conductor **1228** in mechanical and electrical contact with the shaft retainer **1206** (or in some cases with an end of the shaft **1202**, such as when the shaft extends through the shaft retainer (not shown)). As shown, the spring-biased conductor **1228** may include a shear plate that is spring-biased about an axis **1238**, which axis **1238** is perpendicular to and radially outward from a second axis **1240** of the shaft **1202**. By way of example, the shear plate is shown to be circular, although the shear plate could also have other shapes. In some embodiments, the surface of the shear plate that abuts the shaft retainer **1206** or shaft end may be hardened (e.g., with a PVD deposited coating of cobalt chromium (CoCr or hard chromium)) to mitigate the likelihood of the shaft retainer **1206** or shaft end wearing through the shear plate after multiple rotations or translations of the shaft **1202**. The shear plate (and in some cases the entirety of the spring-biased conductor **1228**) may be plated with gold or another material to improve electrical conductivity (e.g., prior to coating the shear plate with a hardener). In some cases, the spring-biased conductor **1228** may be formed (e.g., stamped or bent) from a piece of metal (e.g., stainless steel). In other cases, the spring-biased conductor **1228** may be formed in other ways. The length and thickness of the shear plate, perpendicular to the axis of the shaft **1202**, can be optimized to provide a balance between a high enough spring constant to ensure good electrical contact between the shear plate and the shaft retainer **1206** or shaft end (even during rotation of the shaft **1202**), on one hand, and a low enough spring constant to mitigate the likelihood that the shaft retainer **1206** or shaft end will wear through the shear plate (or through a coating thereon). A flat or relatively flat shear plate can reduce the dimension of the crown assembly **1200** along the axis **1240** of the shaft **1202**.

In some embodiments, a majority or entirety of the shaft **1202**, shaft retainer **1206**, or crown **1204** may be coated with a non-conductive coating, but for an external conductive surface of the crown **1204** and a portion of the shaft **1202** or shaft retainer **1206** that contacts the spring-biased conductor **1228**.

When the shaft **1202** is translatable, translation of the shaft **1202** into the housing **1242** (e.g., into the housing of a watch body) may cause the spring-biased conductor **1228** (or the shear plate thereof) to deform. However, the spring bias of the spring-biased conductor **1228** may cause the spring-biased conductor **1228** (or the shear plate thereof) to maintain electrical contact with the shaft retainer or shaft end, regardless of whether the shaft **1202** is in a first position or a second position with reference to translation of the shaft **1202**. The spring-biased conductor **1228** may be electrically connected to a circuit, such as a circuit formed on or in a substrate **1230** such as a flex circuit or printed circuit board (PCB). In some cases, the spring-biased conductor **1228** may be surface-attached to the circuit substrate **1230** (such as soldered or otherwise mechanically connected, for example by using a surface-mount technology process), which circuit substrate **1230** may be supported by the rigid support member (or sub-housing frame member) **1226**. A conductive grease may be deposited between the shaft retainer **1206** or shaft **1202** and the shear plate or other member of the spring-biased conductor **1228**. The circuit

may be in electrical communication with the crown **1204** via the spring-biased conductor **1228**, the shaft retainer **1206**, and the shaft **1202** (or when an end of the shaft **1202** protrudes through the shaft retainer **1206**, the circuit may be in electrical communication with the crown **1204** via the spring-biased conductor **1228** and the shaft **1202**).

A tactile (tac) switch **1252**, such as a dome switch, may be electrically connected to the circuit and mechanically connected to the circuit substrate **1230**. In some cases, the tac switch **1252** may be surface-attached to the circuit substrate **1230** (such as soldered or otherwise mechanically connected). The shear plate of the spring-biased conductor **1228** may be positioned between the shaft retainer **1206** and the tac switch **1252**. The tac switch **1252** may be actuated or change state in response to translation of the shaft **1202**. Thus, when a user presses on the crown **1204**, the shaft **1202** may translate into the housing **1242** (e.g., into the housing of a watch body) and actuate the tac switch **1252**, placing the tac switch **1252** in one of a number of states. When the user releases pressure on the crown **1204** or pulls the crown **1204** outward from the housing **1242**, the tac switch **1252** may retain the state in which it was placed when pressed, or advance to another state, or toggle between two states, depending on the type or configuration of the tac switch **1252**.

The circuit to which the tac switch **1252** and spring-biased conductor **1228** are electrically connected may be part of, or electrically connected to, one or more circuits that carry portions of an optical encoder **1232** and other circuit elements, such as an interface **1234** to the electrodes described with reference to FIGS. **5**C, **5**D, **5**E, **6-8**, **9**A-**9**C, & **10**A-**10**D, or a processor that receives and processes signals received from or provided to the crown **1204** or other electrodes. By way of example, FIG. **12**A shows a circuit **1236** (e.g., a flex circuit or PCB) to which a set of one or more light emitters and light detectors of an optical encoder **1232** is connected. The light emitter(s) may illuminate an encoder pattern or other rotating portion of the optical encoder **1232**, which encoder pattern or other rotating portion of the optical encoder **1232** may be carried on (e.g., formed on, printed on, etc.) the shaft retainer **1206**. The light detector(s) may receive reflections of the light emitted by the light emitter(s), and a processor may determine a direction of rotation, speed of rotation, angular position, translation, or other state(s) of the crown **1204** and shaft **1202**.

The spring-biased conductor **1228** may be connected to a processor. The processor may be attached or coupled to one or more of the circuits shown in FIG. **12**A. The processor may determine whether a user is touching the crown **1204**, or determine a biological parameter of the user based on a signal received from or provided to the user via the crown **1204**, or determine other parameters based on signals received from or provided to the crown **1204**. In some cases, the processor may operate the crown and electrodes described in FIGS. **5**C, **5**D, **5**E, **6-8**, **9**A-**9**C, **10**A-**10**D, **11**, **12**A, & **12**B as an electrocardiogram and provide an ECG to a user of a watch including the crown and electrodes.

In an alternate embodiment of the crown assembly **1200** shown in FIGS. **12**A & **12**B, the spring-biased conductor **1228** may include a conductive brush that is biased to contact a side of the shaft **1202** or a side of the shaft retainer **1206**. The conductive brush may maintain electrical contact with the shaft **1202** or shaft retainer **1206** through rotation or translation of the shaft **1202**, and may be electrically connected to a circuit such as the circuit that supports the tac switch **1352**.

FIG. **13** shows a cross-section of a crown assembly **1300** as viewed from an edge of a watch body (e.g., an edge to which a watch band might be attached). The crown assembly **1300** shown in FIG. **13** differs from the crown assembly **1200** shown in FIGS. **12**A & **12**B in that the crown **1302** has a somewhat different configuration. For example, the crown **1302** has a conductive crown body **1304** surrounded by a non-conductive ring **1306**. The non-conductive ring **1306** may be attached to the conductive crown body **1304** by an adhesive **1308**. Alternatively, the ring **1306** may be conductive, and may be insulated from the conductive crown body **1304** by the adhesive **1308** (e.g., when the adhesive **1308** is non-conductive) or electrically connected to the conductive crown body **1304** (e.g., when the adhesive **1308** is conductive).

As shown in FIG. **13**, the crown assembly **1300** may be positioned adjacent a transparent cover **1310** (e.g., a carrier) under which a display may be attached, such that the display is at least partially or fully within the housing. In some cases, the display may be a touch-sensitive display. In some embodiments, the display may also be a force-sensitive display. FIG. **13** shows one example of a force sensor **1312** for a force-sensitive display, in which a compressible gasket **1314** is bounded by first and second capacitive plates **1316**, **1318** and positioned between the carrier **1310** and the housing **1242**.

FIG. **14** shows a cross-section of a crown assembly **1400**, as may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. Similarly to the crown assemblies **1200** and **1300** shown in FIGS. **12**A, **12**B, & **13**, the crown assembly **1400** is an example of the crown assembly **1100** shown in FIG. **11**.

The crown assembly **1400** is similar to the crown assembly **1200** in that its crown **1402** has a conductive crown body **1404** surrounded by an inner ring **1406** of non-conductive material and an outer ring **1408** of conductive material. The conductive crown body **1404** may be formed of a conductive ceramic or stainless steel, and may be coated in a PVD deposited layer of SUS or DLC, or an ED layer of AlTiN or CrSiCN, and may function as an electrode. The non-conductive inner ring **1406** may help prevent shorting of the crown **1402** to the housing **1242**, and may be formed of a plastic or elastomer, for example. The conductive outer ring **1408** may be formed of the same or different material(s) as the conductive crown body **1404**.

The non-conductive inner ring **1406** may extend from an outer surface of the crown **1402** to under a portion of the conductive crown body **1404**. In this manner, the non-conductive inner ring **1406** may prevent the conductive crown body **1404** from contacting the collar **1208** when the crown **1402** is translated toward the housing **1242**.

The conductive outer ring **1408** may extend from an outer surface of the crown **1402** to under a portion of the non-conductive inner ring **1406**. In this manner, if the housing **1242** is grounded and the conductive outer ring **1408** contacts the housing **1242**, the conductive outer ring **1408** may be grounded to the housing **1242**.

In contrast to the crown assemblies **1200** and **1300**, the crown assembly **1400** has an insulator **1410** (e.g., a non-conductive element, layer, or coating) applied to at least one surface of the collar **1208** (e.g., to at least a portion of the surface or surfaces that face an underside of the conductive crown body **1404**). The insulator **1410** may further prevent the conductive crown body **1404** from contacting the collar **1208** when the crown **1402** is translated toward the housing **1242** and may provide increased separation resistance between the collar **1208** and the crown **210**. In some

embodiments, the insulator **1410** may include a layer of plastic that is overmolded (e.g., LCP overmolded) on at least a portion (or all) of the collar **1208** that faces the crown **210** (or a plastic element that is placed over or adhered to at least a portion (or all) of the collar **1208**, or a coating that is applied to at least a portion of the collar **1208**). In some embodiments, the plastic may extend to adjacent surfaces of the housing **206**, or into the central opening in the collar **1208**. In some embodiments, the insulator **1410** may include a coating (e.g., an electro-deposited (ED) acrylic-based polymer coating). Alternatively or additionally, an insulator (e.g., an element, layer, or coating) may be applied to the underside of the conductive crown body **1404**, or to surfaces of the shaft **1202** that face the collar **1208** and/or housing **206**. Alternatively, the collar **1208** may be formed from plastic or another material that is non-conductive or otherwise electrically isolates the conductive crown body **1404** of the crown **1402**, or the shaft **1202**, from other conductive components of the crown assembly **1500**.

In any of the crown assemblies **1200**, **1300**, **1400** described in the present disclosure, the crown **1204**, **1302**, or **1402** may alternately be a monolithic structure and not include additional conductive or non-conductive rings, or may include a single non-conductive (e.g., plastic) ring surrounding a conductive central portion.

Turning now to the implementation of an electrode on a button, FIG. **15** shows an example cross-section of a button assembly **1500**. The button assembly **1500** may be an example of a button assembly included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B.

The button assembly **1500** may include a conductive button cap **1502**. The conductive button cap **1502** may be retained within an opening in a housing by a button cap retention assembly **1504**. The button cap retention assembly **1504**, or parts thereof, may be conductive. By way of example, the housing is shown to be the housing **206** of the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B. The button cap retention assembly **1504** may be attached to the housing **206** and extend through the opening in the housing **206**. In some embodiments, the button cap retention assembly **1504** may include a first component **1506** that is inserted through the opening from one side of the housing **206**, and a second component **1508** that fastens to the first component **1506** on the other side of the housing **206** (e.g., by threads, screws, solder, or an adhesive).

A set of one or more insulators **1510** (e.g., electrical insulators) may electrically insulate the button cap retention assembly **1504** from the housing **206**. The insulator **1510** may also electrically insulate the conductive button cap **1502** from the housing **206**. Although the insulator **1510** is generally shown in FIG. **15** as a singular annular seal around the perimeter of the button assembly **1500**, the insulator **1510** may alternatively include more than one element or be positioned elsewhere within the button assembly **1500**, as described with reference to FIGS. **16**A, **16**B, **17**A, **17**B, **18**A, & **18**C.

The conductive button cap **1502** may translate toward and away from the housing **206**, and may be in electrical contact with the button cap retention assembly **1504** during all phases of translation. When the conductive button cap **1502** is pressed by a user and translates toward the housing **206**, a tactile switch **1512** may be actuated (e.g., switched between two or more states). A shaft **1514** may extend from an interior surface of, or be formed integrally with, the conductive button cap **1502** and a depressible surface of the

tactile switch **1512**. The tactile switch **1512** and shaft **1514**, or other elements not shown in FIG. **15** (e.g., springs), may bias the conductive button cap **1502** in an outwardly translated position.

The conductive button cap **1502** may function as an electrode, and an electrical signal may be routed between the conductive button cap **1502** and a circuit **1516**, at least in part, via the button cap retention assembly **1504**. In some embodiments, the button cap retention assembly **1504**, tactile switch **1512**, and circuit **1516** may be attached to a common substrate **1518**.

Because the signals received by or propagated from the conductive button cap **1502** may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the conductive button cap **1502** can have a significant impact on the ability of the circuit **1516** to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the button assembly **1500**. The materials, positions, electrical connections to, and electrical routing paths for the button assembly **1500** can also determine how well the button assembly **1500** receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the conductive button cap **1502** and internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the button assembly **1500** operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator **1510** may be positioned to prevent moisture from electrically shorting the conductive button cap **1502** to the housing **206**, or the housing **206** may be grounded to provide electrical shielding for some or all of the signals propagated through the button assembly **1500**.

More detailed examples of the button assembly **1500** described with reference to FIG. **15** are shown in FIGS. **16**A, **16**B, **17**A, **17**B, **18**A, & **18**B.

Turning now to FIGS. **16**A & **16**B, there is shown an example of a button assembly **1600** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. FIG. **16**A shows an exploded view of the button assembly **1600**, and FIG. **16**B shows an assembled cross-section of the button assembly **1600**, as viewed from the front or rear face of an electronic device such as the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, and **4**B.

The button assembly **1600** is an example of the button assembly **1500** shown in FIG. **15**, and includes components corresponding to the conductive button cap **1502**, button cap retention assembly **1504**, insulator **1510**, and tactile switch **1512**.

The button assembly **1600** may be at least partially within an opening **1602** in a housing **1604** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and attached to the housing or an internal structure. In some cases, and as shown, the housing **1604** may include a cavity **1606** (FIG. **16**B) defined by a sidewall **1608** and a ledge **1610**. The ledge **1610** may surround the opening **1602**, and the sidewall **1608** may surround the ledge **1610**.

The button assembly **1600** may include a conductive button cap **1612**. The conductive button cap **1612** may be retained by a button cap retention assembly **1614**, and may be translatable toward and away from the housing **1604**. The button cap retention assembly **1614** may extend through the opening **1602** and be attached to the housing **1604**. In some

examples, the button cap retention assembly **1614** may include a bracket **1616** that overlaps the ledge **1610** interior to the housing **1604**, and a retainer **1618** that overlaps the ledge **1610** exterior to the housing **1604**. The retainer **1618** may be mechanically attached to the bracket **1616** by a set of screws **1620** or other mechanical fastener. The screws **1620** may be inserted into through-holes in the bracket **1616** and screwed into threaded holes in the retainer **1618**, clamping the ledge **1610** between the bracket **1616** and the retainer **1618**.

The conductive button cap **1612** may have an exterior surface **1622**, a sidewall or set of sidewalls **1624** parallel to the sidewall **1608** of the cavity **1606**, and an inward facing lip or set of lips **1626** (FIG. **16**B) that extends between the retainer **1618** and the ledge **1610** and toward a center axis of the conductive button cap **1612**. A set of one or more coil springs **1628** or other spring-biased members may be positioned between an outer surface of the retainer **1618** and an underside of the conductive button cap **1612**, and may bias the conductive button cap **1612** in an outward state of translation.

The button cap retention assembly **1614**, and in particular the retainer **1618**, may have a through-hole **1629** defined therein, with an axis of the through-hole **1629** extending perpendicular to the opening **1602** in the housing **1604**. A shaft **1630** may be positioned within the through-hole **1629**, and may translate toward and away from the housing **1604**. The shaft **1630** may be mechanically connected to the conductive button cap **1612**, or may be biased to contact the conductive button cap **1612**. By way of example, the shaft **1630** may be non-conductive. In a state of rest, the shaft **1630** and conductive button cap **1612** may be biased in an outward state of translation (i.e., away from the opening **1602**) by the coil springs **1628** and/or a spring-biased tactile switch **1632**. When a user presses the conductive button cap **1612** toward the housing **1604**, the press may overcome the bias provided by the coil springs **1628** and/or tactile switch **1632**, and pressure on the conductive button cap **1612** may be transferred to the shaft **1630**, which translates toward the housing **1604** and presses on the tactile switch **1632** to change the state of the tactile switch **1632** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **1632** may be aligned with an axis of the shaft **1630** and attached to the bracket **1616** using an adhesive **1634** (e.g., a conductive PSA).

In some embodiments, a gasket **1636** (e.g., an O-ring) may be positioned between the shaft **1630** and the through-hole. The shaft **1630** may have a circumferential groove **1638** in which a portion of the gasket **1636** is seated so that the gasket **1636** moves in a predictable way in response to movement of the shaft **1630**. In some examples, the gasket **1636** may be non-conductive.

The button assembly **1600** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly **1614** from the housing **1604**, and electrically insulate the conductive button cap **1612** from the housing **1604**. For example, the button assembly **1600** may include a first electrical insulator, such as a sleeve **1640** (or set of shims), positioned between the conductive button cap **1612** and the sidewall **1608** (or set of sidewalls) of the cavity **1606** in the housing **1604**. In some cases, the sleeve **1640** may include a closed-shape sidewall and an inward facing lip **1642** (FIG. **16**B). In other cases, the sleeve **1640** may not include the inward facing lip **1642** or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter gasket (e.g., an insulator including the lip **1642** but not the sidewall). A second electrical insulator may include an adhesive **1644** (e.g., an adhesive ring) applied to a surface of the retainer **1618** facing the housing **1604**, or to the outer surface of the ledge **1610** within the cavity **1606**. In some cases, the adhesive **1644** may include a PSA. A gasket or seal **1646**, external to the housing **1604**, may be bonded to the adhesive **1644**. The adhesive **1644** and seal **1646** may be compressed when the screws **1620** are tightened to clamp the housing **1604** between the bracket **1616** and retainer **1618** of the button cap retention assembly **1614**. A third electrical insulator may include a spacer **1648**, internal to the housing **1604**, positioned between the bracket **1616** and the housing **1604**. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly **1614** (e.g., the bracket **1616** and the retainer **1618**) from the housing **1604**. The first electrical insulator may electrically insulate the conductive button cap **1612** from the housing **1604**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **1612** or button cap retention assembly **1614** from the housing **1604**.

In use, a signal may be applied to, or received from, the button cap retention assembly **1614** (e.g., to/from the bracket **1616**) via a circuit (e.g., a flex circuit or other circuit element **1650**) that is electrically connected to the bracket **1616** (e.g., via a conductive adhesive **1652**). A signal may travel through the conductive button cap **1612**, coil springs **1628**, retainer **1618**, screws **1620**, and bracket **1616** via a first electrical path, or through the conductive button cap **1612**, retainer **1618**, screws **1620**, and bracket **1616** via a second electrical path. Although the second electrical path may be broken when the conductive button cap **1612** is pressed by a user, the conductive button cap **1612** may remain in electrical contact with the button cap retention assembly **1614** during all states of translation (e.g., via the first electrical path).

With reference to FIGS. **17**A & **17**B, there is shown another example of a button assembly **1700** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. FIG. **17**A shows an exploded view of the button assembly **1700**, and FIG. **17**B shows an assembled cross-section of the button assembly **1700**, as viewed from the front or rear face of an electronic device such as the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B.

The button assembly **1700** is an example of the button assembly **1500** shown in FIG. **15**, and includes components corresponding to the conductive button cap **1502**, button cap retention assembly **1504**, insulator **1510**, and tactile switch **1512**.

The button assembly **1700** may be at least partially within an opening **1702** in a housing **1704** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and may be attached to any the housing or an internal structure. In some cases, and as shown, the housing **1704** may include a cavity **1706** (FIG. **17**B) defined by at least one sidewall (e.g., a single sidewall **1708** or set of sidewalls) and a ledge **1710**. The ledge **1710** may define the opening **1702**, and the sidewall **1708** may surround the ledge **1710**.

The button assembly **1700** may include a conductive button cap **1712** (or button cap having a conductive portion). The conductive button cap **1712** may be retained by a button cap retention assembly **1714** (or button retainer), and may be translatable toward and away from the housing **1704**. The button cap retention assembly **1714** may extend through the

opening **1702** and be connected or otherwise attached to the housing **1704**. In some examples, the button cap retention assembly **1714** may include a bracket **1716** that overlaps the ledge **1710** interior to the housing **1704**, and a retainer **1718** that overlaps the ledge **1710** exterior to the housing **1704**. The retainer **1718** may be mechanically attached to the bracket **1716** by a set of screws **1720** or other mechanical fastener. The screws **1720** may be inserted into through-holes in the bracket **1716** and screwed into threaded holes in the retainer **1718**, clamping the ledge **1710** between the bracket **1716** and the retainer **1718**.

The conductive button cap **1712** may have an exterior surface **1722**, a sidewall or set of sidewalls **1724** parallel to the sidewall **1708** of the cavity **1706**, and an inward facing lip or set of lips **1726** (FIG. **19**) that extends between the retainer **1718** and the ledge **1710** and toward a center axis of the conductive button cap **1712**. A set of one or more coil springs **1728** or other spring-biased members may be positioned between an outer surface of the retainer **1718** and an underside of the conductive button cap **1712**, and may bias the conductive button cap **1712** in an outward state of translation.

The button cap retention assembly **1714**, and in particular the retainer **1718**, may have a through-hole **1729** defined therein, with an axis of the through-hole **1729** extending perpendicular to the opening **1702** in the housing **1704**. A shaft **1730** may be positioned within the through-hole **1729**, and may translate toward and away from the housing **1704**. The shaft **1730** may be mechanically connected to the conductive button cap **1712**, or may be biased to contact the conductive button cap **1712**. In some cases, the shaft **1730** may be mechanically and electrically connected to the conductive button cap **1712**. In a state of rest, the shaft **1730** and conductive button cap **1712** may be biased in an outward state of translation (i.e., away from the opening **1702**) by the coil springs **1728** and/or a spring-biased tactile switch **1732**. In some cases, a shim **1734**, such as a non-conductive shim, may be attached to an end of the shaft **1730** facing the tactile switch **1732**. When a user presses the conductive button cap **1712** toward the housing **1704**, the press may overcome the bias provided by the coil springs **1728** and/or tactile switch **1732**, and pressure on the conductive button cap **1712** may be transferred to the shaft **1730**, which translates toward the housing **1704** and presses on the tactile switch **1732** to change the state of the tactile switch **1732** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **1732** may be aligned with an axis of the shaft **1730** and attached to the bracket **1716** using an adhesive **1736** (e.g., a conductive PSA).

In some embodiments, a gasket **1738** (e.g., an O-ring) may be positioned between the shaft **1730** and the through-hole. The shaft **1730** may have a circumferential groove **1740** (FIG. **17**B) in which a portion of the gasket **1738** is seated so that the gasket **1738** moves in a predictable way in response to movement of the shaft **1730**. In some examples, the gasket **1738** may be conductive.

The button assembly **1700** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly **1714** from the housing **1704**, and electrically insulate the conductive button cap **1712** from the housing **1704**. For example, the button assembly **1700** may include a first electrical insulator, such as a sleeve **1742** (or set of shims), positioned between the conductive button cap **1712** and the sidewall **1708** (or set of sidewalls) of the cavity **1706** in the housing **1704**. In some cases, the sleeve **1742** may include a closed-shape sidewall and an inward facing lip **1744** (FIG. **18**B). In other cases, the sleeve **1742** may not include the inward facing lip **1744** or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter gasket (e.g., an insulator including the lip **1744** but not the sidewall). A second electrical insulator may include an adhesive **1746** (e.g., an adhesive ring) applied to a surface of the retainer **1718** facing the housing **1704**, or to the outer surface of the ledge **1710** within the cavity **1706**. In some cases, the adhesive **1746** may include a PSA. A gasket or seal **1748**, external to the housing **1704**, may be bonded to the adhesive **1746**. The adhesive **1746** and seal **1748** may be compressed when the screws **1720** are tightened to clamp the housing **1704** between the bracket **1716** and retainer **1718** of the button cap retention assembly **1714**. A third electrical insulator may include a spacer **1750**, internal to the housing **1704**, positioned between the bracket **1716** and the housing **1704**. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly **1714** (e.g., the bracket **1716** and the retainer **1718**) from the housing **1704**. The first electrical insulator may electrically insulate the conductive button cap **1712** from the housing **1704**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **1712** or button cap retention assembly **1714** from the housing **1704**.

In use, a signal may be applied to, or received from, the button cap retention assembly **1714** (e.g., to/from the bracket **1716**) via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the bracket **1716** (e.g., as described with reference to FIG. **17**A). A signal may travel through the conductive button cap **1712**, shaft **1730**, conductive gasket **1738**, retainer **1718**, screws **1720**, and bracket **1716** via a first electrical path. The signal may also travel through the conductive button cap **1712**, coil springs **1728**, retainer **1718**, screws **1720**, and bracket **1716** via a second electrical path, or through the conductive button cap **1712**, retainer **1718**, screws **1720**, and bracket **1716** via a third electrical path. Although the third electrical path may be broken when the conductive button cap **1712** is pressed by a user, the conductive button cap **1712** may remain in electrical contact with the button cap retention assembly **1714** during all states of translation (e.g., via the first and second electrical paths).

FIGS. **18**A & **18**B show another example of a button assembly **2000** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. FIG. **18**A shows an exploded view of the button assembly **1800**, and FIG. **18**B shows an assembled cross-section of the button assembly **1800**, as viewed from the front or rear face of an electronic device such as the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B.

The button assembly **1800** is an example of the button assembly **1500** shown in FIG. **15**, and includes components corresponding to the conductive button cap **1502**, button cap retention assembly **1504**, insulator **1510**, and tactile switch **1512**.

The button assembly **1800** may be at least partially within an opening **1802** in a housing **1804** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing **1804** may include a cavity **1806** (FIG. **18**B) defined by at least one sidewall (e.g., a single sidewall **1808** or set

of sidewalls) and a ledge **1810**. The ledge **1810** may define the opening **1802**, and the sidewall **1808** may surround the ledge **1810**.

The button assembly **1800** may include a conductive button cap **1812** (or button cap having a conductive portion). The conductive button cap **1812** may be retained by a button cap retention assembly **1814** (or button retainer), and may be translatable toward and away from the housing **1804**. The button cap retention assembly **1814** may extend through the opening **1802** and be connected or otherwise attached to the housing **1804**. In some examples, the button cap retention assembly **1814** may include a bracket **1816** that overlaps the ledge **1810** interior to the housing **1804**, and a retainer **1818** that overlaps the ledge **1810** exterior to the housing **1804**. The retainer **1818** may be mechanically attached to the bracket **1816** by a set of screws **1820** or other mechanical fastener. The screws **1820** may be inserted into through-holes in the bracket **1816** and screwed into threaded holes in the retainer **1818**, clamping the ledge **1810** between the bracket **1816** and the retainer **1818**.

The conductive button cap **1812** may have an exterior surface **1822**, a sidewall or set of sidewalls **1824** parallel to the sidewall **1808** of the cavity **1806**, and an inward facing lip or set of lips **1826** (FIG. **18**B) that extends between the retainer **1818** and the ledge **1810** and toward a center axis of the conductive button cap **1812**. A set of one or more coil springs **1828** or other spring-biased members may be positioned between an outer surface of the retainer **1818** and an underside of the conductive button cap **1812**, and may bias the conductive button cap **1812** in an outward state of translation.

The button cap retention assembly **1814**, and in particular the retainer **1818**, may have a through-hole **1829** defined therein, with an axis of the through-hole **1829** extending perpendicular to the opening **1802** in the housing **1804**. A shaft **1830** may be positioned within the through-hole **1829**, and may translate toward and away from the housing **1804**. The shaft **1830** may be mechanically connected to the conductive button cap **1812**, or may be biased to contact the conductive button cap **1812**. In some cases, the shaft **1830** may be mechanically and electrically connected to the conductive button cap **1812**. In a state of rest, the shaft **1830** and conductive button cap **1812** may be biased in an outward state of translation (i.e., away from the opening **1802**) by the coil springs **1828** and/or a spring-biased tactile switch **1832**. In some cases, a spring-biased conductor (e.g., a conductive shear plate **1834**) may extend between the tactile switch **1832** and an end of the shaft **1830** facing the tactile switch **1832**. When a user presses the conductive button cap **1812** toward the housing **1804**, the press may overcome the bias provided by the coil springs **1828** and/or tactile switch **1832**, and pressure on the conductive button cap **1812** may be transferred to the shaft **1830**, which translates toward the housing **1804** and presses on the tactile switch **1832** to change the state of the tactile switch **1832** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **1832** may be aligned with an axis of the shaft **1830** and attached to the bracket **1816** using an adhesive **1836** (e.g., a conductive PSA).

In some embodiments, a gasket **1838** (e.g., an O-ring) may be positioned between the shaft **1830** and the through-hole. The shaft **1830** may have a circumferential groove **1840** in which a portion of the gasket **1838** is seated so that the gasket **1838** moves in a predictable way in response to movement of the shaft **1830**. In some examples, the gasket **1838** may be non-conductive.

The button assembly **1800** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the button cap retention assembly **1814** from the housing **1804**, and electrically insulate the conductive button cap **1812** from the housing **1804**. For example, the button assembly **1800** may include a first electrical insulator, such as a sleeve **1842** (or set of shims), positioned between the conductive button cap **1812** and the sidewall **1808** (or set of sidewalls) of the cavity **1806** in the housing **1804**. In some cases, the sleeve **1842** may include a closed-shape sidewall and an inward facing lip **1844** (FIG. **18**B). In other cases, the sleeve **1842** may not include the inward facing lip **1844** or have a sidewall that does not define a closed shape. In other cases, the first electrical insulator may be a planar perimeter gasket (e.g., an insulator including the lip **1844** but not the sidewall). A second electrical insulator may include an adhesive **1846** (e.g., an adhesive ring) applied to a surface of the retainer **1818** facing the housing **1804**, or to the outer surface of the ledge **1810** within the cavity **1806**. In some cases, the adhesive **1846** may include a PSA. A gasket or seal **1848**, external to the housing **1804**, may be bonded to the adhesive **1846**. The adhesive **1846** and seal **1848** may be compressed when the screws **1820** are tightened to clamp the housing **1804** between the bracket **1816** and retainer **1818** of the button cap retention assembly **1814**. A third electrical insulator may include a spacer **1850**, internal to the housing **1804**, positioned between the bracket **1816** and the housing **1804**. The third electrical insulator, in conjunction with the first and/or second electrical insulator, may electrically insulate the conductive button cap retention assembly **1814** (e.g., the bracket **1816** and the retainer **1818**) from the housing **1804**. The first electrical insulator may electrically insulate the conductive button cap **1812** from the housing **1804**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **1812** or button cap retention assembly **1814** from the housing **1804**.

The shear plate **1834** may be formed from a conductive sheet that is stamped, molded, or otherwise shaped to form an open (shown) or closed (not shown) shape conductive perimeter **1852** and an elevated tab **1854** (e.g., a tab having an end positioned in a different plane than the conductive perimeter **1852**). The conductive perimeter **1852** may be positioned between the bracket **1816** and spacer **1850**, such that the conductive perimeter **1852** and shear plate **1834** are electrically insulated from the housing **1804**. The shear plate **1834** deforms in response to translation of the shaft **1830**.

In use, a signal may be applied to, or received from, the button cap retention assembly **1814** (e.g., to/from the bracket **1816**) via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the bracket **1816** (e.g., as described with reference to FIG. **16**B). A signal may travel through the conductive button cap **1812**, shaft **1830**, shear plate **1834**, and bracket **1816** via a first electrical path. The signal may also travel through the conductive button cap **1812**, coil springs **1828**, retainer **1818**, screws **1820**, and bracket **1816** via a second electrical path, or through the conductive button cap **1812**, retainer **1818**, screws **1820**, and bracket **1816** via a third electrical path. Although the third electrical path may be broken when the conductive button cap **1812** is pressed by a user, the conductive button cap **1812** may remain in electrical contact with the button cap retention assembly **1814** during all states of translation (e.g., via the first and second electrical paths).

FIG. **19** shows an example elevation of a button assembly **1900**. The button assembly **1900** may be an example of a

button assembly included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B.

The button assembly **1900** may include a conductive button cap **1902**. The conductive button cap **1902** may be retained within an opening in a housing by a button cap retention assembly **1904** (e.g., a button retainer). The button cap retention assembly **1904**, or parts thereof, may be conductive. By way of example, the housing is shown to be the housing **206** of the watch body **202** described with reference to FIGS. **2**A-**2**C, **3**, **4**A, & **4**B. The button cap retention assembly **1904** may be attached to the housing **206** and extend through the opening in the housing **206**. In some embodiments, the button cap retention assembly **1904** may include a first component **1906** that is inserted through the opening from one side of the housing **206**, and a second component **1908** that fastens to the first component **1906** on the other side of the housing **206** (e.g., by threads, screws, solder, or an adhesive).

A set of one or more insulators **1910** (e.g., electrical insulators) may electrically insulate the conductive button cap **1902** from the button cap retention assembly **1904**. The insulator **1910** may also electrically insulate the conductive button cap **1902** from the housing **206**. Although the insulator **1910** is generally shown in FIG. **19** to include a non-conductive liner **1910***a* on an underside of the conductive button cap **1902**, a non-conductive sleeve **1910***b* positioned between the conductive button cap **1902** and the housing **206**, and a non-conductive sleeve **1910***c* positioned between the button cap retention assembly **1904** and a shaft **1914**, the insulator **1910** may alternatively include more or fewer elements, which elements may be positioned in different locations within the button assembly **1900**, as described with reference to FIGS. **20**, **21**, & **22**.

The conductive button cap **1902** may translate toward and away from the housing **206**, and may be insulated from the button cap retention assembly **1904** during all phases of translation. When the conductive button cap **1902** is pressed by a user and translates toward the housing **206**, a tactile switch **1912** may be actuated (e.g., switched between two or more states). The shaft **1914** may extend between an interior surface of the conductive button cap **1902** and a depressible surface of the tactile switch **1912**. The tactile switch **1912** and shaft **1914**, or other elements not shown in FIG. **19** (e.g., springs), may bias the conductive button cap **1902** in an outwardly translated position.

The conductive button cap **1902** may function as an electrode, and an electrical signal may be routed between the conductive button cap **1902** and a circuit **1916**, at least in part, via the shaft **1914**. In some embodiments, the button cap retention assembly **1904**, tactile switch **1912**, and circuit **1916** may be attached to a common substrate **1918**.

Because the signals received by or propagated from the conductive button cap **1902** may be low voltage or low amplitude signals, the materials, positions, electrical connections to, and electrical routing paths for an electrode formed on or by the conductive button cap **1902** can have a significant impact on the ability of the circuit **1916** to discern useful signals representing an ECG or other biological parameter of a person wearing an electronic device including the button assembly **1900**. The materials, positions, electrical connections to, and electrical routing paths for the button assembly **1900** can also determine how well the button assembly **1900** receives voltages/signals from a person's skin (e.g., a SNR of a device-to-user interface through which the voltages/signals pass); how well voltages/signals are transferred between the conductive button cap **1902** and internal components of an electronic device (e.g., a voltage/signal propagation SNR); and how well the button assembly **1900** operates in the face of environmental factors, such as temperature, humidity, moisture, electromagnetic radiation, dust, and so on. In some cases, the insulator **1910** may be positioned to prevent moisture from electrically shorting the conductive button cap **1902** to the housing **206**, or the housing **206** may be grounded to provide electrical shielding for some or all of the signals propagated through the button assembly **1900**.

More detailed examples of the button assembly **1900** described with reference to FIG. **19** are shown in FIGS. **20**, **21**, & **22**.

Referring now to FIG. **20**, there is shown an assembled cross-section of another example of a button assembly **2000** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. The button assembly **2000** may be at least partially within an opening **2002** in a housing **2004** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing **2004** may include a cavity **2006** defined by at least one sidewall (e.g., a single sidewall **2008** or set of sidewalls) and a ledge **2010**. The ledge **2010** may define the opening **2002**, and the sidewall **2008** may surround the ledge **2010**.

The button assembly **2000** may include a conductive button cap **2012** (or button cap having a conductive portion). The conductive button cap **2012** may be retained by a button cap retention assembly **2014** (or button retainer), and may be translatable toward and away from the housing **2004**. The button cap retention assembly **2014** may extend through the opening **2002** and be connected or otherwise attached to the housing **2004**. In some examples, the button cap retention assembly **2014** may include a bracket **2016** that overlaps the ledge **2010** interior to the housing **2004**, and a retainer **2018** that overlaps the ledge **2010** exterior to the housing **2004**. The retainer **2018** may be mechanically attached to the bracket **2016** by a set of screws **2020** or other mechanical fastener. The screws **2020** may be inserted into through-holes in the bracket **2016** and screwed into threaded holes in the retainer **2018**, clamping the ledge **2010** between the bracket **2016** and the retainer **2018**.

The conductive button cap **2012** may have an exterior surface **2022**, a sidewall or set of sidewalls **2024** parallel to the sidewall **2008** of the cavity **2006**, and an inward facing lip or set of lips **2026** that extends between the retainer **2018** and the ledge **2010** and toward a center axis of the conductive button cap **2012**. A set of one or more coil springs **2028** or other spring-biased members may be positioned between an outer surface of the retainer **2018** and an underside of the conductive button cap **2012**, and may bias the conductive button cap **2012** in an outward state of translation.

The button cap retention assembly **2014**, and in particular the retainer **2018**, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening **2002** in the housing **2004**. A shaft **2030** may be positioned within the through-hole, and may translate toward and away from the housing **2004**. The shaft **2030** may be mechanically and electrically connected to the conductive button cap **2012**, or may be biased to contact the conductive button cap **2012**. In a state of rest, the shaft **2030** and conductive button cap **2012** may be biased in an outward state of translation (i.e., away from the opening **2002**) by the coil springs **2028** and/or a spring-biased tactile switch **2032**. In some cases, a shim **2034**, such as a non-conductive shim, may be attached to an end of the shaft **2030** facing the tactile

switch **2032**. When a user presses the conductive button cap **2012** toward the housing **2004**, the press may overcome the bias provided by the coil springs **2028** and/or tactile switch **2032**, and pressure on the conductive button cap **2012** may be transferred to the shaft **2030**, which translates toward the housing **2004** and presses on the tactile switch **2032** to change the state of the tactile switch **2032** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **2032** may be aligned with an axis of the shaft **2030** and attached to the bracket **2016** using an adhesive **2036** (e.g., a non-conductive PSA).

In some embodiments, a gasket **2038** (e.g., an O-ring) may be positioned between the shaft **2030** and the through-hole. In some cases, the gasket **2038** may be positioned between a first non-conductive liner **2044** and a second non-conductive liner **2046**. In some examples, the gasket **2038** may be non-conductive.

The button assembly **2000** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap **2012** from the button cap retention assembly **2014** and housing **2004**. For example, the button assembly **2000** may include a first electrical insulator, such as a sleeve **2042** (or set of shims), positioned between the conductive button cap **2012** and the sidewall **2008** (or set of sidewalls) of the cavity **2006** in the housing **2004**. In some cases, the sleeve **2042** may include a closed-shape sidewall. In other cases, the sleeve **2042** may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner **2044** between an interior surface of the conductive button cap **2012** and the button cap retention assembly **2014**. In some cases, the non-conductive liner **2044** may be press-fit or adhesively bonded to the interior surface of the conductive button cap **2012**. Alternatively, the non-conductive liner **2044** may be press-fit or adhesively bonded to an exterior surface of the retainer **2018**. In some embodiments, the non-conductive liner **2044** may extend into the through-hole, between the shaft **2030** and the button cap retention assembly **2014** (e.g., between the shaft **2030** and the retainer **2018**). A third electrical insulator may include a second non-conductive liner **2046**, positioned in the through-hole between the shaft **2030** and the retainer **2018**, below the gasket **2038**. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap **2012** from the button cap retention assembly **2014** (e.g., from the retainer **2018**). The first electrical insulator may electrically insulate the conductive button cap **2012** from the housing **2004**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **2012** from the button cap retention assembly **2014** or housing **2004**.

A conductive flexure **2048** may be coupled to, but insulated from, the bracket **2016**, and positioned (e.g., angled) to contact the end of the shaft **2030** that faces the tactile switch **2032**. The conductive flexure **2048** may be spring-biased to contact the end of the shaft **2030**, and may be spring-biased to remain in contact with the end of the shaft **2030** during all states of translation of the shaft **2030**.

In use, a signal may be applied to, or received from, the conductive button cap **2012** via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the conductive flexure **2048**. A signal may travel through the conductive button cap **2012**, shaft **2030**, and conductive flexure **2048**.

FIG. **21** shows an assembled cross-section of another example of a button assembly **2100** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. The button assembly **2100** may be at least partially within an opening **2102** in a housing **2104** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing **2104** may include a cavity **2106** defined by at least one sidewall (e.g., a single sidewall **2108** or set of sidewalls) and a ledge **2110**. The ledge **2110** may define the opening **2102**, and the sidewall **2108** may surround the ledge **2110**.

The button assembly **2100** may include a conductive button cap **2112** (or button cap having a conduction portion). The conductive button cap **2112** may be retained by a button cap retention assembly **2114** (or button retainer), and may be translatable toward and away from the housing **2104**. The button cap retention assembly **2114** may extend through the opening **2102** and be connected or otherwise attached to the housing **2104**. In some examples, the button cap retention assembly **2114** may include a bracket **2116** that overlaps the ledge **2110** interior to the housing **2104**, and a retainer **2118** that overlaps the ledge **2110** exterior to the housing **2104**. The retainer **2118** may be mechanically attached to the bracket **2116** by a set of screws **2120** or other mechanical fastener. The screws **2120** may be inserted into through-holes in the bracket **2116** and screwed into threaded holes in the retainer **2118**, clamping the ledge **2110** between the bracket **2116** and the retainer **2118**.

The conductive button cap **2112** may have an exterior surface **2122**, a sidewall or set of sidewalls **2124** parallel to the sidewall **2108** of the cavity **2106**, and an inward facing lip or set of lips **2126** that extends between the retainer **2118** and the ledge **2110** and toward a center axis of the conductive button cap **2112**.

The button cap retention assembly **2114**, and in particular the retainer **2118**, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening **2102** in the housing **2104**. A shaft **2128** may be positioned within the through-hole, and may translate toward and away from the housing **2104**. The shaft **2128** may be mechanically and electrically connected to the conductive button cap **2112**, or may be biased to contact the conductive button cap **2112**. In a state of rest, the shaft **2128** and conductive button cap **2112** may be biased in an outward state of translation (i.e., away from the opening **2102**) by a conductive flexure **2130** or other spring-biased member positioned between the bracket **2116** and an end of the shaft **2128** that faces the bracket **2116**.

The button cap retention assembly **2114**, and in particular the retainer **2118**, may also have a second through-hole formed therein, with an axis of the second through-hole extending perpendicular to the opening **2102** in the housing **2104**. A piston **2132** may be positioned within the through-hole, and may translate toward and away from the housing **2104**. In some cases, a shim **2134**, such as a non-conductive shim, may be attached to an end of the piston **2132** facing a spring-biased tactile switch **2136**. When a user presses the conductive button cap **2112** toward the housing **2104**, the press may overcome the bias provided by the conductive flexure **2130** and/or tactile switch **2136**, and pressure on the conductive button cap **2112** may be transferred to the piston **2132**, which translates toward the housing **2104** and presses on the tactile switch **2136** to change the state of the tactile switch **2136** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **2136** may

be aligned with an axis of the piston **2132** and attached to the bracket **2116** using an adhesive **2138** (e.g., a non-conductive PSA).

In some embodiments, a first gasket **2140** (e.g., an O-ring) may be positioned between the shaft **2128** and the first through-hole, and a second gasket **2142** (e.g., an O-ring) may be positioned between the piston **2132** and the second through-hole. In some cases, the first gasket **2140** may be positioned between a first non-conductive liner **2150** and a second non-conductive liner **2152**. In some cases, the piston **2132** may have a circumferential groove **2146** in which a portion of the second gasket **2142** is seated so that the second gasket **2142** moves in a predictable way in response to movement of the piston **2132**. In some examples, the first and second gaskets **2140**, **2142** may be non-conductive.

The button assembly **2100** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap **2112** from the button cap retention assembly **2114** and housing **2104**. For example, the button assembly **2100** may include a first electrical insulator, such as a sleeve **2148** (or set of shims), positioned between the conductive button cap **2112** and the sidewall **2108** (or set of sidewalls) of the cavity **2106** in the housing **2104**. In some cases, the sleeve **2148** may include a closed-shape sidewall. In other cases, the sleeve **2148** may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner **2150** between an interior surface of the conductive button cap **2112** and the button cap retention assembly **2114**. In some cases, the non-conductive liner **2150** may be press-fit or adhesively bonded to the interior surface of the conductive button cap **2112**. Alternatively, the non-conductive liner **2150** may be press-fit or adhesively bonded to an exterior surface of the retainer **2118**. In some embodiments, the non-conductive liner **2150** may extend into the through-hole, between the shaft **2128** and the button cap retention assembly **2114** (e.g., between the shaft **2128** and the retainer **2118**). A third electrical insulator may include a second non-conductive liner **2152**, positioned in the through-hole between the shaft **2128** and the retainer **2118**, below the gasket **2140**. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap **2112** from the button cap retention assembly **2114** (e.g., from the retainer **2118**). The first electrical insulator may electrically insulate the conductive button cap **2112** from the housing **2104**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **2112** from the button cap retention assembly **2114** or housing **2104**.

In use, a signal may be applied to, or received from, the conductive button cap **2112** via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the conductive flexure **2130**. A signal may travel through the conductive button cap **2112**, shaft **2128**, and conductive flexure **2130**.

FIG. **22** shows an assembled cross-section of another example of a button assembly **2200** that may be included in any of the electronic devices described with reference to FIG. **1**A, **1**B, **2**A-**2**C, **3**, **4**A, or **4**B. The button assembly **2200** may be at least partially within an opening **2202** in a housing **2204** (e.g., an opening in the housing described with reference to FIG. **2**A, **2**C, **3**, **4**A, or **4**B), and may be attached to the housing or an internal structure such as a support. In some cases, and as shown, the housing **2204** may include a cavity **2206** defined by at least one sidewall (e.g., a single sidewall **2208** or set of sidewalls) and a ledge **2210**. The ledge **2210** may define the opening **2202**, and the sidewall **2208** may surround the ledge **2210**.

The button assembly **2200** may include a conductive button cap **2212** (or button cap having a conductive portion). The conductive button cap **2212** may be retained by a button cap retention assembly **2214** (or button retainer), and may be translatable toward and away from the housing **2204**. The button cap retention assembly **2214** may extend through the opening **2202** and be connected or otherwise attached to the housing **2204**. In some examples, the button cap retention assembly **2214** may include a bracket **2216** that overlaps the ledge **2210** interior to the housing **2204**, and a retainer **2218** that overlaps the ledge **2210** exterior to the housing **2204**. The retainer **2218** may be mechanically attached to the bracket **2216** by a set of screws **2220** or other mechanical fastener. The screws **2220** may be inserted into through-holes in the bracket **2216** and screwed into threaded holes in the retainer **2218**, clamping the ledge **2210** between the bracket **2216** and the retainer **2218**.

The conductive button cap **2212** may have an exterior surface **2222**, a sidewall or set of sidewalls **2224** parallel to the sidewall **2208** of the cavity **2206**, and an inward facing lip or set of lips **2226** that extends between the retainer **2218** and the ledge **2210** and toward a center axis of the conductive button cap **2212**.

The button cap retention assembly **2214**, and in particular the retainer **2218**, may have a through-hole defined therein, with an axis of the through-hole extending perpendicular to the opening **2202** in the housing **2204**. A shaft **2228** may be positioned within the through-hole, and may translate toward and away from the housing **2204**. The shaft **2228** may be mechanically and electrically connected to the conductive button cap **2212**, or may be biased to contact the conductive button cap **2212**. In a state of rest, the shaft **2228** and conductive button cap **2212** may be biased in an outward state of translation (i.e., away from the opening **2202**) by a conductive spring (e.g., a coil spring **2230**) or other spring-biased member positioned between the bracket **2216** and an end of the shaft **2228** that faces the bracket **2216**.

The button cap retention assembly **2214**, and in particular the retainer **2218**, may also have a second through-hole formed therein, with an axis of the second through-hole extending perpendicular to the opening **2202** in the housing **2204**. A piston **2232** may be positioned within the through-hole, and may translate toward and away from the housing **2204**. When a user presses the conductive button cap **2212** toward the housing **2204**, the press may overcome the bias provided by the coil spring **2230** and/or tactile switch **2234**, and pressure on the conductive button cap **2212** may be transferred to the piston **2232**, which translates toward the housing **2204** and presses on the tactile switch **2234** to change the state of the tactile switch **2234** (e.g., from ON to OFF or vice versa, from one functional state to another, etc.). The tactile switch **2234** may be aligned with an axis of the piston **2232** and attached to the bracket **2216** using an adhesive **2236** (e.g., a non-conductive PSA).

In some embodiments, a first gasket **2238** (e.g., an O-ring) may be positioned between the shaft **2228** and the first through-hole, and a second gasket **2240** (e.g., an O-ring) may be positioned between the piston **2232** and the second through-hole. In some cases, the first gasket **2238** may be positioned between a first non-conductive liner **2248** and a second non-conductive liner **2250**. In some cases, the piston **2232** may have a circumferential groove **2244** in which a portion of the second gasket **2240** is seated so that the second gasket **2240** moves in a predictable way in response

to movement of the piston **2232**. In some examples, the first and second gaskets **2238**, **2240** may be non-conductive.

The button assembly **2200** may further include a set of electrical insulators (i.e., one or more electrical insulators), which set of electrical insulators may electrically insulate the conductive button cap **2212** from the button cap retention assembly **2214** and housing **2204**. For example, the button assembly **2200** may include a first electrical insulator, such as a sleeve **2246** (or set of shims), positioned between the conductive button cap **2212** and the sidewall **2208** (or set of sidewalls) of the cavity **2206** in the housing **2204**. In some cases, the sleeve **2246** may include a closed-shape sidewall. In other cases, the sleeve **2246** may also include an inward facing lip, or may not have a sidewall that defines a closed shape. A second electrical insulator may include a non-conductive liner **2248** between an interior surface of the conductive button cap **2212** and the button cap retention assembly **2214**. In some cases, the non-conductive liner **2248** may be press-fit or adhesively bonded to the interior surface of the conductive button cap **2212**. Alternatively, the non-conductive liner **2248** may be press-fit or adhesively bonded to an exterior surface of the retainer **2218**. In some embodiments, the non-conductive liner **2248** may extend into the through-hole, between the shaft **2228** and the button cap retention assembly **2214** (e.g., between the shaft **2228** and the retainer **2218**). A third electrical insulator may include a second non-conductive liner **2250**, positioned in the through-hole between the shaft **2228** and the retainer **2218**, below the gasket **2238**. The second electrical insulator, in some cases in conjunction with the third electrical insulator, may electrically insulate the conductive button cap **2212** from the button cap retention assembly **2214** (e.g., from the retainer **2218**). The first electrical insulator may electrically insulate the conductive button cap **2212** from the housing **2204**. In some embodiments, additional or different electrical insulators may electrically insulate the conductive button cap **2212** from the button cap retention assembly **2214** or housing **2204**.

In use, a signal may be applied to, or received from, the conductive button cap **2212** via a circuit (e.g., a flex circuit or other circuit element) that is electrically connected to the coil spring **2230**. A signal may travel through the conductive button cap **2212**, shaft **2228**, and coil spring **2230**.

FIG. **23** shows a schematic **2300** of an electronic device, such as an electronic watch, that may be used for acquiring an ECG or other biological parameter from a user of the electronic device. In some cases, the electronic device may include a watch body. As shown, the electronic device may include a first electrode **2302** on a carrier **2304**, an optional second electrode **2306** on the carrier **2304**, and a third electrode **2308** on the surface of a user-rotatable crown **2310** (or alternatively, on the surface of a button). The third electrode **2308** may be operable to be contacted by a finger of a user while the first electrode **2302** (and optional second electrode **2306**) are positioned against a user's skin (e.g., against the wrist of the user). A processor **2312**, which in some cases may be provided in an integrated circuit (IC), an application-specific integrated circuit (ASIC), a field programmable gate array (FPGA), a system in package (SIP), a system on a chip (SOC), etc., may be operable to acquire an ECG from the user, or determine another biological parameter of, the user. The ECG or other biological parameter may be determined based on voltages at the first, optional second, and third electrodes **2302**, **2306**, **2308** while the user is in contact with the first, optional second, and third electrodes **2302**, **2306**, **2308**.

In some cases, voltages may be sensed at just the first and third electrodes **2302**, **2308**. In other cases, the second electrode **2306** may be grounded to the electronic device, thereby the user to the electronic device, and the voltage at the second electrode **2306** (i.e., the ground voltage) may be used to remove noise generated by the electronic device or other environmental sources from the signals measured at the first and third electrodes **2302**, **2308**. This may result in more accurate readings (or processing) of the first and third voltages.

As shown, a signal or voltages at the first electrode **2302** may be amplified by a first amplifier **2314**, and a signal or voltages at the third electrode **2308** may be amplified by a second amplifier **2316**.

FIG. **24** shows an example method **2400** of determining a biological parameter of a user wearing an electronic watch or other wearable electronic device, such as a watch or wearable electronic device described herein.

At block **2402**, a ground voltage is optionally applied to a user via a first electrode on the electronic device. The first electrode may be on an exterior surface of a carrier that forms part of a housing of the electronic device. The operation(s) at **2402** may be performed, for example, by the processor described with reference to FIG. **24**, using one of the electrodes described with reference to FIGS. **1**B, **2**A-**2**C, **3**, **4**A-**4**C, **5**D, **5**E, **6**-**8**, **9**A-**9**C, **10**A-**10**D, & **23**.

At block **2404**, a first voltage or signal is sensed at a second electrode on the electronic device. The second electrode may also be on the exterior surface of the carrier. The operation(s) at **2404** may be performed, for example, by the processor described with reference to FIG. **24**, using one of the electrodes described with reference to FIGS. **1**B, **2**A-**2**C, **3**, **4**A-**4**C, **5**D, **5**E, **6**-**8**, **9**A-**9**C, **10**A-**10**D, **11**, **12**A, **12**B, **13**, **14**, **15**, **16**A, **16**B, **17**A, **17**B, **18**A, **18**B, **19**, **20**, **21**, **22**, & **23**.

At block **2406**, a second voltage or signal is sensed at a third electrode on the electronic device. The third electrode may be on a user-rotatable crown of the electronic device, or on a button of the electronic device, or on another surface of the housing of the electronic device. In some embodiments, the ground voltage is applied and the first voltage or signal is sensed on a wrist of one arm of the user, and the second voltage or signal is sensed on a fingertip of the user (with the fingertip belonging to a finger on a hand on the other arm of the user). The operation(s) at **2406** may be performed, for example, by the processor described with reference to FIG. **24**, using one of the electrodes described with reference to FIGS. **1**B, **2**A-**2**C, **3**, **4**A-**4**C, **5**D, **5**E, **6**-**8**, **9**A-**9**C, **10**A-**10**D, **11**, **12**A, **12**B, **13**, **14**, **15**, **16**A, **16**B, **17**A, **17**B, **18**A, **18**B, **19**, **20**, **21**, **22**, & **23**.

At block **2408**, the biological parameter of the user may be determined from the optional ground voltage, the first voltage or signal, and the second voltage or signal. The ground voltage may provide a reference for the first and second voltages or signals, or may otherwise be used to reject noise from the first and second voltages or signals. When the first and second voltages are obtained from different parts of the user's body, the biological parameter may be an electrocardiogram for the user. The operation(s) at **2408** may be performed, for example, by the processor described with reference to FIG. **25**.

FIG. **25** shows a sample electrical block diagram of an electronic device **2500**, which electronic device may in some cases take the form of any of the electronic watches or other wearable electronic devices described with reference to FIGS. **1**-**23**, or other portable or wearable electronic devices. The electronic device **2500** can include a display **2505** (e.g., a light-emitting display), a processor **2510**, a

power source **2515**, a memory **2520** or storage device, a sensor **2525**, and an input/output (I/O) mechanism **2530** (e.g., an input/output device, input/output port, or haptic input/output interface). The processor **2510** can control some or all of the operations of the electronic device **2500**. The processor **2510** can communicate, either directly or indirectly, with some or all of the components of the electronic device **2500**. For example, a system bus or other communication mechanism **2535** can provide communication between the processor **2510**, the power source **2515**, the memory **2520**, the sensor **2525**, and the input/output mechanism **2530**.

The processor **2510** can be implemented as any electronic device capable of processing, receiving, or transmitting data or instructions. For example, the processor **2510** can be a microprocessor, a central processing unit (CPU), an application-specific integrated circuit (ASIC), a digital signal processor (DSP), or combinations of such devices. As described herein, the term "processor" is meant to encompass a single processor or processing unit, multiple processors, multiple processing units, or other suitably configured computing element or elements.

It should be noted that the components of the electronic device **2500** can be controlled by multiple processors. For example, select components of the electronic device **2500** (e.g., a sensor **2525**) may be controlled by a first processor and other components of the electronic device **2500** (e.g., the display **2505**) may be controlled by a second processor, where the first and second processors may or may not be in communication with each other. In some cases, the processor **2510** may determine a biological parameter of a user of the electronic device, such as an ECG for the user.

The power source **2515** can be implemented with any device capable of providing energy to the electronic device **2500**. For example, the power source **2515** may be one or more batteries or rechargeable batteries. Additionally or alternatively, the power source **2515** can be a power connector or power cord that connects the electronic device **2500** to another power source, such as a wall outlet.

The memory **2520** can store electronic data that can be used by the electronic device **2500**. For example, the memory **2520** can store electrical data or content such as, for example, audio and video files, documents and applications, device settings and user preferences, timing signals, control signals, and data structures or databases. The memory **2520** can be configured as any type of memory. By way of example only, the memory **2520** can be implemented as random access memory, read-only memory, Flash memory, removable memory, other types of storage elements, or combinations of such devices.

The electronic device **2500** may also include one or more sensors **2525** positioned almost anywhere on the electronic device **2500**. The sensor(s) **2525** can be configured to sense one or more type of parameters, such as but not limited to, pressure, light, touch, heat, movement, relative motion, biometric data (e.g., biological parameters), and so on. For example, the sensor(s) **2525** may include a heat sensor, a position sensor, a light or optical sensor, an accelerometer, a pressure transducer, a gyroscope, a magnetometer, a health monitoring sensor, and so on. Additionally, the one or more sensors **2525** can utilize any suitable sensing technology, including, but not limited to, capacitive, ultrasonic, resistive, optical, ultrasound, piezoelectric, and thermal sensing technology. In some examples, the sensors **2525** may include one or more of the electrodes described herein (e.g., one or more electrodes on an exterior surface of a carrier that forms part of a housing for the electronic device **2500** and/or an electrode on a crown, button, or other housing member of the electronic device).

The I/O mechanism **2530** can transmit and/or receive data from a user or another electronic device. An I/O device can include a display, a touch sensing input surface, one or more buttons (e.g., a graphical user interface "home" button), one or more cameras, one or more microphones or speakers, one or more ports such as a microphone port, and/or a keyboard. Additionally or alternatively, an I/O device or port can transmit electronic signals via a communications network, such as a wireless and/or wired network connection. Examples of wireless and wired network connections include, but are not limited to, cellular, Wi-Fi, Bluetooth, IR, and Ethernet connections.

As discussed above, graphics displayed on the electronic devices herein may be manipulated through inputs provided to the crown. FIGS. **26**A-**28**B generally depict examples of changing a graphical output displayed on an electronic device through inputs provided by force and/or rotational inputs to a crown assembly of the device. This manipulation (e.g., selection, acknowledgement, motion, dismissal, magnification, and so on) of a graphic may result in changes in operation of the electronic device and/or graphical output displayed by the electronic device. Although specific examples are provided and discussed, many operations may be performed by rotating and/or applying force to a crown such as the examples described above. Accordingly, the following discussion is by way of example and not limitation.

FIG. **26**A depicts an example electronic device **2600** (shown here as an electronic watch) having a crown **2602**. The crown **2602** may be similar to the examples described above, and may receive force inputs along a first lateral direction, a second lateral direction, or an axial direction of the crown. The crown **2602** may also receive rotational inputs. A display **2606** provides a graphical output (e.g., shows information and/or other graphics). In some embodiments, the display **2606** may be configured as a touch-sensitive display capable of receiving touch and/or force input. In the current example, the display **2606** depicts a list of various items **2661**, **2662**, **2663**, all of which are example graphics.

FIG. **26**B illustrates how the graphical output shown on the display **2606** changes in a first manner as the crown **2602** rotates, partially or completely (as indicated by the arrow **2660**). Rotating the crown **2602** causes the list to scroll or otherwise move on the screen, such that the first item **2661** is no longer displayed, the second and third items **2662**, **2663** each move upwards on the display, and a fourth item **2664** is now shown at the bottom of the display. This is one example of a scrolling operation that can be executed by rotating the crown **2602**. Such scrolling operations may provide a simple and efficient way to depict multiple items relatively quickly and in sequential order. A speed of the scrolling operation may be controlled by the amount of rotational force applied to the crown **2602** and/or the speed at which the crown **2602** is rotated. Faster or more forceful rotation may yield faster scrolling, while slower or less forceful rotation yields slower scrolling. The crown **2602** may receive an axial force (e.g., a force inward toward the display **2606** or watch body) to select an item from the list, in certain embodiments.

FIGS. **27**A and **27**B illustrate an example zoom operation. The display **2706** depicts a picture **2766** at a first magnification, shown in FIG. **27**A; the picture **2766** is yet another example of a graphic. A user may apply a translating force

(e.g., a force along the z-axis) or a lateral force (e.g., a force along the x-axis) to the crown **2702** of the electronic device **2700** (illustrated by arrow **2765**), and in response the display may change a graphic in a second manner, such as zooming into the picture **2766** so that a portion **2767** of the picture is shown at an increased magnification. This is shown in FIG. **27**B. The direction of zoom (in vs. out) and speed of zoom, or location of zoom, may be controlled through force applied to the crown **2702**, and particularly through the direction of applied force and/or magnitude of applied force. Applying force to the crown **2702** in a first direction may zoom in, while applying force to the crown **2702** in an opposite direction may zoom out. Alternately, rotating or applying force to the crown **2702** in a first direction may change the portion of the picture subject to the zoom effect. In some embodiments, applying an axial or translating force (e.g., a force along the z-axis) to the crown **2702** may toggle between different zoom modes or inputs (e.g., direction of zoom vs. portion of picture subject to zoom), or otherwise change the displayed graphic in a second manner. In yet other embodiments, applying force to the crown **2702** along another direction, such as along the y-axis, may return the picture **2766** to the default magnification shown in FIG. **27**A.

FIGS. **28**A and **28**B illustrate possible use of the crown **2802** to change an operational state of the electronic device **2800** or otherwise toggle between inputs. Turning first to FIG. **28**A, the display **2806** depicts a question **2868**, namely, "Would you like directions?" As shown in FIG. **28**B, a lateral force may be applied to the crown **2802** (illustrated by arrow **2870**) to answer the question. Applying force to the crown **2802** provides an input interpreted by the electronic device **2800** as "yes," and so "YES" is displayed as a graphic **2869** on the display **2806**. Applying force to the crown **2802** in an opposite direction may provide a "no" input. Both the question **2868** and graphic **2869** are examples of graphics.

In the embodiment shown in FIGS. **28**A and **28**B, the force applied to the crown **2802** is used to directly provide the input, rather than select from options in a list (as discussed above with respect to FIGS. **26**A and **26**B).

As mentioned previously, force or rotational input to a crown of an electronic device may control many functions beyond those listed here. The crown may receive distinct force or rotational inputs to adjust a volume of an electronic device, a brightness of a display, or other operational parameters of the device. A force or rotational input applied to the crown may rotate to turn a display on or off, or turn the device on or off. A force or rotational input to the crown may launch or terminate an application on the electronic device. Further, combinations of inputs to the crown may likewise initiate or control any of the foregoing functions, as well.

In some cases, the graphical output of a display may be responsive to inputs applied to a touch-sensitive display (e.g., displays **2606**, **2706**, **2806**, and the like) in addition to inputs applied to a crown. The touch-sensitive display may include or be associated with one or more touch and/or force sensors that extend along an output region of a display and which may use any suitable sensing elements and/or sensing techniques to detect touch and/or force inputs applied to the touch-sensitive display. The same or similar graphical output manipulations that are produced in response to inputs applied to the crown may also be produced in response to inputs applied to the touch-sensitive display. For example, a swipe gesture applied to the touch-sensitive display may cause the graphical output to move in a direction corresponding to the swipe gesture. As another example, a tap gesture applied to the touch-sensitive display may cause an item to be selected or activated. In this way, a user may have multiple different ways to interact with and control an electronic watch, and in particular the graphical output of an electronic watch. Further, while the crown may provide overlapping functionality with the touch-sensitive display, using the crown allows for the graphical output of the display to be visible (without being blocked by the finger that is providing the touch input).

As another example, and of the inputs described in FIGS. **26**A-**28**B may be used to select, initiate, or display an ECG, or otherwise begin the operation of determining an ECG or launching an ECG application.

As described above, one aspect of the present technology is the gathering and use of data available from various sources, including the gathering and use of biological parameters of a user, to monitor or improve the user's health or fitness. The present disclosure contemplates that in some instances, this gathered data may include personal information data that uniquely identifies a specific person, or can be used to contact, locate, or identify a specific person. Such personal information data can include demographic data, location-based data, telephone numbers, email addresses, twitter IDs, home addresses, data or records relating to a user's health or level of fitness (e.g., vital sign measurements, medication information, exercise information), date of birth, or any other identifying or personal information.

The present disclosure recognizes that the use of such personal information data, in the present technology, can be used to the benefit of users. For example, the personal information data can be used to aid a user in monitoring or improving their health or fitness (e.g., biological parameters or health and fitness data may be used to provide insights into a user's general wellness, or may be used as positive feedback to individuals using technology to pursue wellness goals).

The present disclosure contemplates that the entities responsible for the collection, analysis, disclosure, transfer, storage, or other use of such personal information data will comply with well-established privacy policies and/or privacy practices. In particular, such entities should implement and consistently use privacy policies and practices that are generally recognized as meeting or exceeding industry or governmental requirements for maintaining personal information data private and secure. Such policies should be easily accessible by users, and should be updated as the collection and/or use of data changes. Personal information from users should be collected for legitimate and reasonable uses of the entity and not shared or sold outside of those legitimate uses. Further, such collection/sharing should occur after receiving the informed consent of the users. Additionally, such entities should consider taking any needed steps for safeguarding and securing access to such personal information data and ensuring that others with access to the personal information data adhere to their privacy policies and procedures. Further, such entities can subject themselves to evaluation by third parties to certify their adherence to widely accepted privacy policies and practices. In addition, policies and practices should be adapted for the particular types of personal information data being collected and/or accessed and adapted to applicable laws and standards, including jurisdiction-specific considerations. For instance, in the US, collection of or access to certain health data may be governed by federal and/or state laws, such as the Health Insurance Portability and Accountability Act (HIPAA); whereas health data in other countries may be subject to other regulations and policies and should

be handled accordingly. Hence different privacy practices should be maintained for different personal data types in each country.

Despite the foregoing, the present disclosure also contemplates embodiments in which users selectively block the use of, or access to, personal information data. That is, the present disclosure contemplates that hardware and/or software elements can be provided to prevent or block access to such personal information data. For example, in the case of biological parameters or conditions identified therefrom, the present technology can be configured to allow users to select to “opt in” or “opt out” of participation in the collection of personal information data during registration for services or anytime thereafter. In another example, users can select not to provide health or fitness-associated data to the providers of applications or services, or can prevent the transmission of such data from the device on which it is collected or outside a collection of devices that are personal to a user from which the data is obtained. In yet another example, a user can select to limit the length of time health or fitness data, or biological parameters from which such data is derived, is maintained. In addition to providing “opt in” and “opt out” options, the present disclosure contemplates providing notifications relating to the access or use of personal information. For instance, a user may be notified upon downloading an app that their personal information data will be accessed and then reminded again just before personal information data is accessed by the app.

Moreover, it is the intent of the present disclosure that personal information data should be managed and handled in a way to minimize risks of unintentional or unauthorized access or use. Risk can be minimized by limiting the collection of data and deleting data once it is no longer needed. In addition, and when applicable, including in certain health related applications, data de-identification can be used to protect a user’s privacy. De-identification may be facilitated, when appropriate, by removing specific identifiers (e.g., date of birth, etc.), controlling the amount or specificity of data stored (e.g., collecting location data at a city level rather than at an address level), controlling how data is stored (e.g., aggregating data across users), and/or other methods.

Therefore, although the present disclosure broadly covers use of personal information data to implement one or more various disclosed embodiments, the present disclosure also contemplates that the various embodiments can also be implemented without the need for accessing at least some personal information data. That is, the various embodiments of the present technology are not rendered inoperable due to the lack of a portion of such personal information data. For example, biological parameters can be ascertained or stored without associating the biological parameters with information identifying a particular user from which they are obtained, or with a bare minimum amount of personal information, such as non-personal information already available to service providers or publicly available information.

The foregoing description, for purposes of explanation, uses specific nomenclature to provide a thorough understanding of the described embodiments. However, it will be apparent to one skilled in the art that the specific details are not required in order to practice the described embodiments. Thus, the foregoing descriptions of the specific embodiments described herein are presented for purposes of illustration and description. They are not targeted to be exhaustive or to limit the embodiments to the precise forms

disclosed. It will be apparent to one of ordinary skill in the art that many modifications and variations are possible in view of the above teachings.

What is claimed is:

1. An electronic watch comprising:
a housing member;
a display at least partially enclosed by the housing member;
a carrier assembly coupled to the housing member and comprising:
a carrier member formed from a transparent material;
a first electrode positioned on the carrier member, operably coupled to a processor and configured to detect a first voltage; and
a second electrode positioned on the carrier member, operably coupled to the processor and configured to detect a second voltage, the first and second electrodes at least partially surrounding a first region of the carrier member and a second region of the carrier member;
a light emitter positioned below the first region of the carrier member;
a light receiver positioned below the second region of the carrier member and configured to receive light reflected from a wrist;
a third electrode coupled to the housing member, operably coupled to the processor, and configured to detect a third voltage; and
the processor positioned within the electronic watch and configured to determine an electrocardiogram using the first voltage, the second voltage, and the third voltage.

2. The electronic watch of claim **1**, wherein:
the light receiver is a first light receiver;
the electronic watch further comprises a second light receiver; and
the first and second light receivers are configured to measure a heart rate using the light reflected from the wrist.

3. The electronic watch of claim **1**, wherein:
the housing member defines a rectangular outer housing profile;
the display is a rectangular display; and
the carrier member defines a circular outer carrier profile.

4. The electronic watch of claim **1**, wherein:
the first electrode includes a first conductive coating deposited on the carrier member; and
the second electrode includes a second conductive coating deposited on the carrier member.

5. The electronic watch of claim **4**, wherein the first and second conductive coatings include one or more of an aluminum titanium nitride material, a chromium silicon carbon nitride material, or a diamond like carbon material.

6. The electronic watch of claim **4**, wherein:
the first conductive coating is deposited along an exterior surface of the carrier member, an edge of the carrier member, and an interior surface of the carrier member; and
the processor is operably coupled to the first electrode along a portion of the first conductive coating positioned along the interior surface of the carrier member.

7. The electronic watch of claim **1**, wherein:
the electronic watch further comprises a button having a conductive button cap; and
the conductive button cap defines the third electrode.

8. The electronic watch of claim **1**, wherein:

the carrier member includes an opaque ink mask deposited along an inner surface of the carrier member surrounding the first and second regions;

the first and second electrodes are positioned along an exterior surface of the carrier member that is over the opaque ink mask; and

the exterior surface of the carrier member protrudes outward from an external surface of the housing member.

9. A wearable electronic device comprising:

a rectangular housing member defining a rectangular front opening and a circular rear opening;

a cover having a rectangular cover profile and positioned over the rectangular front opening;

a display positioned below the cover;

a carrier assembly coupled to the rectangular housing member and comprising:

a carrier member having a circular carrier profile and positioned over the circular rear opening;

a rear electrode positioned on the carrier member and configured to receive a first voltage signal from a wrist of a user;

an optical sensor system comprising:

an optical emitter positioned below a first region of the carrier member; and

an optical receiver positioned below a second region of the carrier member;

a side electrode positioned along an exterior of the rectangular housing member and configured to receive a second voltage signal from a finger of the user; and

a processor positioned within the wearable electronic device and configured to determine a biological parameter using the first and second voltage signals.

10. The wearable electronic device of claim **9**, wherein:

the rear electrode is a first rear electrode; and

the wearable electronic device further comprises a second rear electrode positioned on the carrier member and configured to ground the wearable electronic device to the user.

11. The wearable electronic device of claim **10**, wherein:

the first rear electrode defines a first arc that partially surrounds the optical sensor system; and

the second rear electrode defines a second arc that partially surrounds the optical sensor system.

12. The wearable electronic device of claim **9**, wherein:

the rear electrode is formed from a conductive coating deposited along an exterior surface of the carrier member; and

the conductive coating extends around an edge of the carrier member and along an inner portion of the carrier member that is internal to the wearable electronic device.

13. The wearable electronic device of claim **9**, wherein the optical sensor system is an optical heart rate sensor that is configured to measure a heart rate of the user.

14. The wearable electronic device of claim **9**, wherein:

the optical sensor system is configured to measure a heart rate of the user; and

the biological parameter is an electrocardiogram (ECG) of the user.

15. A watch comprising:

a housing member;

a display configured to display a graphical output;

a carrier assembly coupled to the housing member and comprising:

a carrier member protruding outward from an external surface of the housing member; and

a rear electrode positioned on the carrier member, the rear electrode operably coupled to a processor and configured to detect a first voltage;

an optical sensor positioned below the carrier member and configured to transmit optical signals through the carrier member;

a side electrode positioned along an exterior of the watch, the side electrode operably coupled to the processor and configured to detect a second voltage; and

the processor positioned within the watch and configured to:

determine a biological parameter; and

cause a change to the graphical output in response to determining the biological parameter.

16. The watch of claim **15**, wherein:

the carrier member defines a circular outer profile;

the optical sensor comprises a light emitter configured to emit light through a first region of the carrier member;

the optical sensor comprises an optical receiver configured to receive reflected light through a second region of the carrier member; and

the rear electrode is positioned along a peripheral region of the carrier member and at least partially surrounds the first and second regions of the carrier member.

17. The watch of claim **15**, wherein:

the rear electrode is a first rear electrode;

the watch further comprises a second rear electrode positioned on the carrier member; and

the first rear electrode and the second rear electrode are defined by a conductive coating deposited on a surface of the carrier member.

18. The watch of claim **17**, wherein the second rear electrode is configured to ground the watch to a portion of a skin of a user wearing the watch.

19. The watch of claim **15**, wherein:

the rear electrode includes a conductive coating that includes one or more of an aluminum titanium nitride or a chromium silicon carbon nitride material; and

the conductive coating extends along an edge of the carrier member and along an interior surface of the carrier member.

20. The watch of claim **15**, wherein:

the watch further comprises a button; and

the side electrode is positioned along a surface of the button.

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